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EXPERIMENTAL AND DESIGN STUDIES

TURBO - RAMJET COMBINATION ENGINE

FINAL REPORT

CALCULATED RESULTS

VOLUME 4

JANUARY 196

AFAPL-TR-66-34
Volume IV

EXPERIMENTAL AND DESIGN STUDIES FOR TURBO-RAMJET COMBINATION ENGINE
Volume IV - Calculated Results

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Technical Report AFAPL-TR-66-34, Volume IV

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FOREWORD

This report was prepared by Nord Aviation, France under Contract AF 61(052)-750 initiated under Project No. 3012, Task No. 301203. The work was administered under the direction of the Air Force Aero Propulsion Laboratory, Turbine Engine Division, with Isak J. Gershon as project engineer.

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained herein. This report has been reviewed and is published only for the exchange and stimulation of ideas.

E C Simpson

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Chief, Turbine Engine Division
Air Force Aero Propulsion Laboratory

AF 61(052)-750 December 1965

EXPERIMENTAL AND DESIGN STUDIES

FOR TURBO-RAMJET COMBINATION ENGINE

Volume 4 - CALCULATED RESULTS

-1-

SUMMARY

In this document, we have produced the calculation results concerning successively :

- in Vol.4.1, the parametric investigation of the engine optimum operating point, that permits one to determine the performance characteristics of the power plant, and the laws of regulation of the internal variable cross-section areas (flow mixer, exit nozzle throat) ;

- in Vol. 4.2, the characteristics of the internal flow : speeds, temperatures, pressures, and flow rate ratios in the different stations.

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FINAL REPORT

EXPERIMENTAL AND DESIGN STUDIES FOR TURBO-RAMJET COMBINATION ENGINE VOLUME 4-1 - PARAMETRIC CALCULATIONS OF PERFORMANCE CHARACTERISTICS

NORD-AVIATION

DEPARTEMENT 'PROPULSEURS'

PARIS (CHATILLON) FRANCE

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SUMMARY

In this document we have calculated the performance characteristics of the combination engine in the three configurations : pure turbofan (subsonic and transonic), turbofan-ramjet combination (moderate supersonic) and pure ramjet (high supersonic rating).

The determination of the operating points led us to perform a parametric study, then to choose the simplest laws of regulation among those yielding performance characteristics close to the optimum.

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TRANSITIONS TF - TFR and TFR - R.

SYMBOLS

Superscripts

' : Indicates primary flow parameters

" : Indicates annular flow parameters

Subscripts

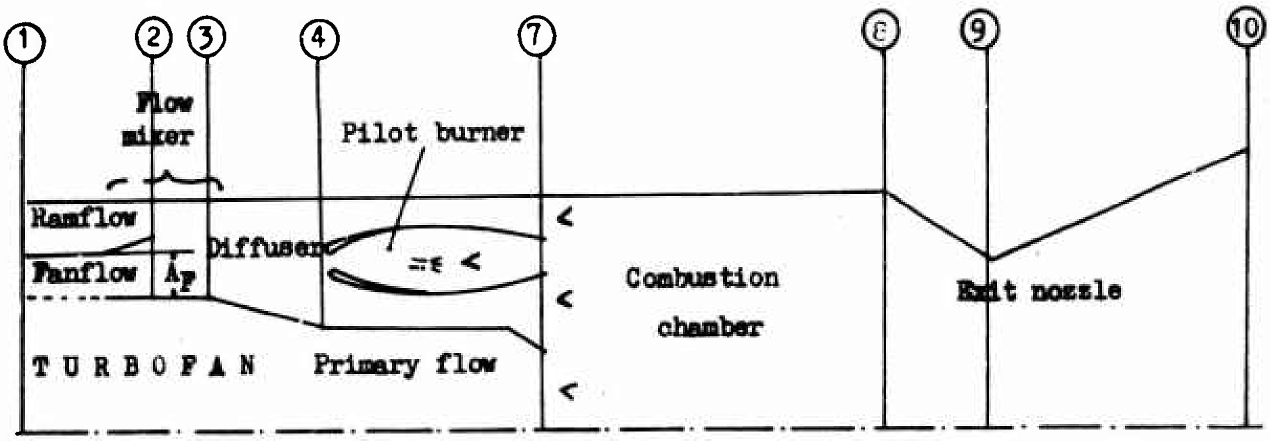
R : Ramjet duct flow

T : Turbofan total flow or turbofan as a whole

F : Turbofan secondary flow

0 : Refers to parameters at upstream infinite

Numerical subscripts refer to various stations as shown in the diagram below



General symbols

A : Cross-sectional area

P : Total pressure

p : Static pressure

T : Total temperature

M : Mach number

Z : Altitude

F_N : Net thrust

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$C_F A$: Thrust coefficient $= F_N / \frac{\gamma_0}{2} p_0 M_0^2$

SFC : Specific fuel consumption

γ : Isentropic coefficient

σ : A_{F2}/A''_3

TIT : Turbine inlet temperature

<u>Special symbols</u>

TF operation : Turbofan operation

TFR operation : Turbofan ramjet operation

R operation : Ramjet operation

.../..

1 - INTRODUCTION

In this report we have successively investigated the following operation cases :

- as a pure turbofan
  - at the turbofan maximum rating, with or without reheat
  - at various reduced ratings of the turbofan, without reheat ;
- as a turbofan-ramjet combination, for two combustion temperatures, at the maximum rating ;
- as a pure ramjet, at four combustion temperatures, with the turbofan stopped.

The basic sectional areas of the engine have been stated in Vol.3.1 - TURBOFAN DATA (para.2) and Vol.3.2 - GENERAL DATA (para.8). In these volumes have also been collected all the thermodynamic data and the partial efficiencies necessary for the calculations. Let the major dimensions be recalled hereunder :

A_{T1} = 7.1 sq.ft	A''_4 = 7.5 sq.ft
A_F = 2.1 sq.ft	A'_7 = 4.0 sq.ft
A''_3 = 3.6 sq.ft	A_7 = 12.6 sq.ft

2 - PURE TURBOFAN OPERATION

2-1 Turbofan at maximum rating

Thermodynamic characteristics were supplied to us by SNECMA under the form of graph systems, for various values of temperature T_1 ranging from 468 °R (260 °K) to 990 °R (550 °K). This enabled us to calculate, for each given altitude, the performance characteristics relating to several Mach numbers. We chose the following calculation points :

.../..

for Z = 0	: M_o = 0	0.79	1.33
for Z = 10,000 ft	: M_o = 0.61	1.02	1.51
for Z = 20,000 ft	: M_o = 0.48	0.89	1.50
for Z = 36,000 ft	: M_o = 1	1.285	1.82

For each point (M_o, Z) the calculation was carried out without, and with reheat (T_8 = 2,700 °R and 3,600 °R).

For $M_o < 1.3$ the performance characteristics were calculated with the simple-convergent configuration ; for $M_o \geqslant 1.3$ they were calculated with a convergent-divergent nozzle whose coefficient was $\varphi = 0.98$.

In each case (with M_o, Z and T_8 being fixed)the performance characteristics depend on parameter $\mathcal{M}_\ell$, which permits to choose the operating point. In fact, as the sectional area of throat A_9 depends on $\mathcal{M}_\ell$, the choice in question is to be effected by control of that area in terms of one or two parameters which remain to be determined.

The calculation results are illustrated in Fig.1 to 36, in which we have plotted

- the thrust coefficient, $C_F A$ (except for sea level static condition, in which case we have plotted F_N)
- the specific fuel consumption, SFC
- the sectional area of the stream tube at upstream infinite, A_o
- the area of the exit throat section, A_9
- the Mach number at the end of the diffuser, M''_4
- the Mach number at the primary exit of the turbofan, M'_7

in terms of parameter $\mathcal{M}_\ell$ and temperature T_8 .

After examination of these curves it can be noticed that, in most cases, the thrust shows a maximum, while the specific consumption decreases in terms of $\mathcal{M}_\ell$. Therefore the optimum operating point must be close to the point of maximum thrust, but with a slightly higher value for $\mathcal{M}_\ell$ so as to reduce the specific consumption.

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For each point (M_o,Z) the conditions $\mathfrak{M}_\ell > \mathfrak{M}_{\ell(Fmax)}$ and $0.95\ F_{max} < F < F_{max}$ define an operating range, therefore two extreme limits for the cross-sectional area of the exit throat, A_9. We thus determined, in plane $A_9\ (r_1)$, a zone in which we looked for a regulation law $A_9\ (r_1)$ valid at any Mach number and altitude. It appears that :

- the zone in question depends only on temperature T_1
- it is not possible to find a single curve independent of T_1 and meeting at the same time the conditions fixed above for F and $\mathfrak{M}_\ell$.

For simplification, we have however adopted a single law comprised, in most cases, in the area defined above ; but this law leads to an increase in the specific fuel consumption for operation at low Mach numbers and with afterburning (this increase attains 4 to 7% in the case when T_1 = 260 °K = 468 °R). The law adopted (see Fig.37) is in the form :

$$A_9 = -1.35\ r_1^2 + 6.7\ r_1 + 2.74$$

The equivalence ratio, r_1, is related to the <u>total</u> air flow, not to the primary air flow. The fuel flow is the sum of the flow injected into the turbofan and that injected into the combustion chamber. This determines one point on each of the curves previously plotted, and consequently we can deduce the graph systems F, SFC (M_o,Z), in the following three cases : without reheat, with T_8 = 2,700 °R and with T_8 = 3,600 °R (see Fig.38 to 40). We have also plotted a system $A_o\ (M_o,Z)$ with and without reheat (see Fig.41) ; this enables us to ascertain that the influence of the heating upon the inlet sectional area is low. Under sea level static conditions the performance characteristics are F = 11,500 lb

SFC = 0.585 lb/lb.hr

when the air flowrate is 235 lb/s, in the case of no-reheat.

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2-2 Turbofan at reduced rating, without reheat

The sets of curves supplied by SNECMA for a given inlet temperature T_1, are valid, as a matter of fact, for a specific ratio TIT/T_1. Therefore, by using for each point (M_0, Z) a graph system corresponding to a temperature T_1 higher than the flight total temperature T_1, we can calculate the performance characteristics at any rating different from the maximum rating.

Thus, under s.l.s. conditions (T_1 = 288 °K = 518.4 °R) we calculated the performance characteristics at three reduced ratings :

TIT/TIT_{max}	:	0.89	0.80	0.695
graph system	:	324	360	420 °K
		(583.2)	(648)	(756 °R)

For each point (M_0, Z) we carried out calculations for three reduced ratings close to 0.9, 0.8 and 0.7.

In Fig. 42 to 65 we have shown the results of these calculations : thrust coefficient, specific consumption and cross-sectional area A_0 and A_9 in terms of parameter m_ℓ .

In the present investigation we have searched for the minimum specific consumption, principally as concerns subsonic operation, since these ratings are used during wait. Therefore we studied particularly the following two points :

M_0 = 0.61 Z = 10,000 ft

M_0 = 0.48 Z = 20,000 ft

The regulation law related to reduced ratings is, as previously, a law in the form $A_9\left[(r_1)_D,\right]$. But here we have considered the equivalence ratio as compared to the primary air flow and not to the total air flow.

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To the turbofan maximum rating corresponds a range of equivalence ratios depending upon the flight conditions. These equivalence ratio values can also be obtained for any reduced rating of the turbofan, but under other flight conditions. It is therefore necessary to provide for an overlap of the two regulation laws, in order that the transfer from one law to the other require no modification of the sectional area A_9, whatever may be the flight conditions under which the turbofan rating reduction occurs. Thus, for high equivalence ratios, we changed the previous law, $A_9\left[(r_i)_D\right]$, into $A_9\left[(r_i)_{D'}\right]$, which leads to :

$$A_9 = 10.52\ (r_i)_{D'} + 0.73$$

This law is used between limits $(r_i)_{D'} > 0.25$ and $TIT = TIT_{max}$, which practically corresponds to N_{HPmax}. When $(r_i)_{D'} < 0.25$ the turbofan rating is always reduced.

Examination of the curves SFC (m_ℓ), in particular for $M_o = 0.48$ and $M_o = 0.61$, shows that if we choose a regulation such that m_ℓ be nearly constant whatever the rating may be, the specific consumptions are close to the minimum. In Fig. 66 and 67, we have plotted $A_9\left[(r_b)_{D'}\right]$; out of the definition, $(r_b)_{D'}$ is proportional to $(r_i)_{D'}$ since the turbofan combustion efficiency was assumed to be constant. On these plates we have found out that it is possible to adopt a linear law :

$$A_9 = 3.9\ (r_i)_{D'} + 2.375 \quad \text{with } (r_i)_{D'} \leqslant 0.25$$

If we study a progressive reduction of the turbofan rating, we therefore come across these phases :

- when $TIT = TIT_{max}$, with or without afterburning, regulation is obtained by the law established in para.2-1,

$$A_9 = -\ 1.35\ (r_i)_D^2 + 6.7\ (r_i)_D + 2.74$$

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- when TIT $< TIT_{max}$, with $(r_i)_{D'} > 0.25$, the law is

$$A_9 = 10.52\ (r_i)_{D'} + 0.73$$

- when TIT $< TIT_{max}$, with $(r_i)_{D'} < 0.25$, the law becomes

$$A_9 = 3.9\ (r_i)_{D'} + 2.375$$

For each system (M_c, Z, TIT/TIT_{max}), we therefrom deduce the operating point, hence the thrust and specific fuel consumption.

We have shown the results under two different forms :

- in Fig. 68 to 71 : specific consumption (thrust) with M_o and TIT/TIT_{max} as parameters, at various altitudes :
  Z = 0, 10,000 ft, 20,000 ft, 36,000 ft
- in Fig. 72 to 74 : thrust and specific consumption in terms of M_o and Z, with TIT/TIT_{max} = 0.9, 0.8, 0.7

We may consider choosing the simplest law, that is to say A_9 = a constant, for the turbofan reduced ratings without afterburning. The value chosen for A_9 would be close to that defined by the maximum rating regulation, in the case of non-heating in the combustion chamber. The basic regulation of the TF 106 turbofan could then be retained without modification : the fuel flow is controlled so that the gas temperature ahead of the HP turbine remain constant, i.e. so that, as a first approximation, the HP rotor r.p.m. keep constant. It should be noticed that such a regulation is not optimized as concerns specific consumption but on the other hand the curves related to the specific consumption are almost even.

3 - TURBOFAN-RAMJET MIXED OPERATION

Our investigation was conducted at an altitude of 36,000 ft; any other calculation at a higher altitude would not have modified the conclusions, but would have led to an increase in the specific fuel consumption because of a decrease in the combustion efficiency.

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In Contract AF 61 (052)-670 : TURBOFAN-RAMJET ENGINE STUDIES, Vol.3.2 - OPERATING FIELD, we showed that the engine operation in the mixed configuration is not possible for M_o = 1.575 at the turbofan maximum rating (with considering the limitations we had imposed and which we have recalled here : $M_{R2} \geqslant 0.1$ and $A_9 / A_8 \leqslant 0.75$) but is possible for M_o = 2. The system of curves at T_1 = 360 °K = 648 °R has enabled us to study an intermediate point at M_o = 1.82 and to specify the utilization limits of the engine operation in the mixed configuration.

Two combustion end temperatures were considered : T_8 = 2 700 °R and 3 600 °R (identical with the reheat temperatures in pure turbofan operation). The calculations were carried out at four Mach numbers :

M_o = 1.82 , 2 , 2.32, 2.536

In the case when M_o = 2.536 we were led to reducing the turbofan rating so as to limit the combustion chamber inlet pressure and temperature to the data supplied by SNECMA. Therefore, in this case, we assumed that TIT/TIT_{max} = 0.9.

Furthermore, in order to study the TF - TFR transition, we had to investigate the case M_o = 1.575, TIT/TIT_{max} = 0.9 (see para.5-1).

The results of these calculations have been shown in Fig. 75, 90 and 91.

In Fig. 76 to 89 we have plotted the thrust coefficient, $C_F A$, the specific consumption and the sectional area of the exit throat, A_9, in terms of M_{R2} and m_ℓ, for the various systems (M_o , T_8). We can therefore deduce, from networks $C_F A$ (σ , m_ℓ) and SFC (σ , m_ℓ) (see Fig. 90 to 107), the iso A_9/A_8 curves, and the limit curve M_{R2} = 0.1. It can be seen that :

- for specific throat section area A_9, the influence of σ upon the performance characteristics is very small ;
- the combination engine operating range increases when temperature T_8 decreases ; this is explained by the fact that heating involves

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an "obturation" of the exit ; in order to abide by the flowrate conservation equation, it is necessary that the throat sectional area be larger for T_8 = 3,600 °R than for T_8 = 2,700 °R. But, as this sectional area has an upper limit, the operating range is the less wide as temperature T_8 is higher ;

- it is not possible to adopt a constant value for σ , since the σ value which would involve correct results at M_o = 1.82 ($\sigma \sim 0.35$) would entail a surge of the turbofan for M_o = 2.54.

Therefore we adopt a linear variation of σ in terms of the Mach number:

$$\sigma = 0.30\, M_o - 0.163 \qquad \text{(see Fig.109)}$$

As a matter of fact, not the Mach number but temperature T_1 must be taken into consideration, which is concealed on account of the fact that all the calculations were carried out at the same altitude. The law of regulation, in terms of T_1, would have the form :

$$\sigma = -\,0.163 + 0.30 \sqrt{\frac{2(T_1 - t_o)}{\gamma_o - 1}}$$

However, considering that the aircraft will fly at these Mach numbers only at altitudes above 36,000 ft, and that it is easier to measure Mach number than temperature T_1, the definition of σ in terms of M_o has been kept as law of regulation.

For the exit throat we have adopted a linear law of regulation in terms of the injected equivalence ratio :

$$A_9 = 7.3\, r_1 + 3.17 \qquad \text{(see Fig. 108)}$$

The fuel flow includes the flow injected into the combustion chamber and into the turbofan.

It can be noted that the variation given by this law for A_9 is almost parallel with that established in the case of the engine operating as a pure turbofan, particularly in the equivalence ratio range corresponding to the interval 2,700 °R $\leqslant T_8 \leqslant$ 3,600 °R (ΔA_9 is on the order of 1.4 sq.ft).

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When T_8 is nearly equal to 3,600 °R this law involves that $0.7 < A_9/A_8 < 0.75$, according to the flight Mach number.

Under these conditions we can have plotted the curves $C_F A$ and SFC (M_o , T_8) at the altitude Z = 36,000 ft (see Fig. 110). Through a correction in the combustion efficiency we have deduced the same curves at the altitude Z = 50,000 ft.

In addition we have plotted in Fig.111 the evolution of A_o in terms of M_o.

4 - PURE RAMJET OPERATION (turbofan stopped)

Three flight altitudes were considered : 50,000 ft , 75,000 ft and 100,000 ft. For each altitude the calculations were carried out at Mach numbers such that the E.A.S. be approximately comprised between 300 and 800 kt.

For each point (M_o, Z) we calculated the performance characteristics at four combustion end temperatures comprised between 1,800 °R and 4,000 °R.

The air flowrate was determined, either by M_{R2} = 0.53 at Mach numbers low enough for A_o to remain smaller than the master-couple (18 sq.ft), or by A_o = 18 sq.ft.

All the calculations were performed under completed expansion condition, with nozzle coefficient $\varphi = 0.98$.

In Fig. 112 to 122 we have exhibited :

- thrust coefficient
- specific fuel consumption
- sectional area of the flow stream tube at upstream infinite, A_o
- exit cross-sectional area, A_{10}
- exit throat section area A_9 in terms of M_o , Z and r_1.

Moreover we studied the influence of the sectional area of the divergent nozzle exit upon the performance characteristics in the case M_o = 4, Z = 100,000 ft, T_8 = 4,000 °R (see Fig. 122). We could

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then find out that a noticeable decrease in the exit sectional area deteriorates but slightly these characteristics. Thus, if A_{10} is reduced by 30 % , the thrust is reduced by 1.3 % , and the specific consumption is increased by 1.3 % .

5 - TRANSITIONAL OPERATIONS

5-1 Transition from TF to TFR operation

We found out that a TF-TFR transition at $M_o = 1.82$ and at the turbofan maximum rating (see Fig.124) would result in a sudden thrust increase for the same combustion end temperature. Consequently we were led to study a TFR operation, but with a reduced rating for the turbofan, and a Mach number lower than 1.82. The performance characteristics were therefore calculated in the following case :

$M_o = 1.575 \quad TIT = 0.9\ TIT_{max} \quad T_8 = 3{,}600\ °R$

The thrust obtained in this configuration is lower than that obtained in the pure turbofan configuration, for the same value of temperature T_8. It is therefore possible, during the transition from TF to TFR operation at $M_o \sim 1.7$, to obtain a thrust curve showing no discontinuity.

However it may be more attractive to try and operate the transition while keeping constant values for A_o and A_9 (see Fig. 125 and 126). As concerns A_o , this keeping is easily obtained by operating the transition at $M_o \sim 1.6$. As for A_9, it would be necessary to reduce the combustion end temperature in TFR operation. Both these conditions result in a reduction of the thrust.

5-2 Transition from TFR to R operation

From a certain Mach number forward it is necessary to diminish the turbofan rating, in order to exceed pressure and temperature limits inside the combustion chamber. As the

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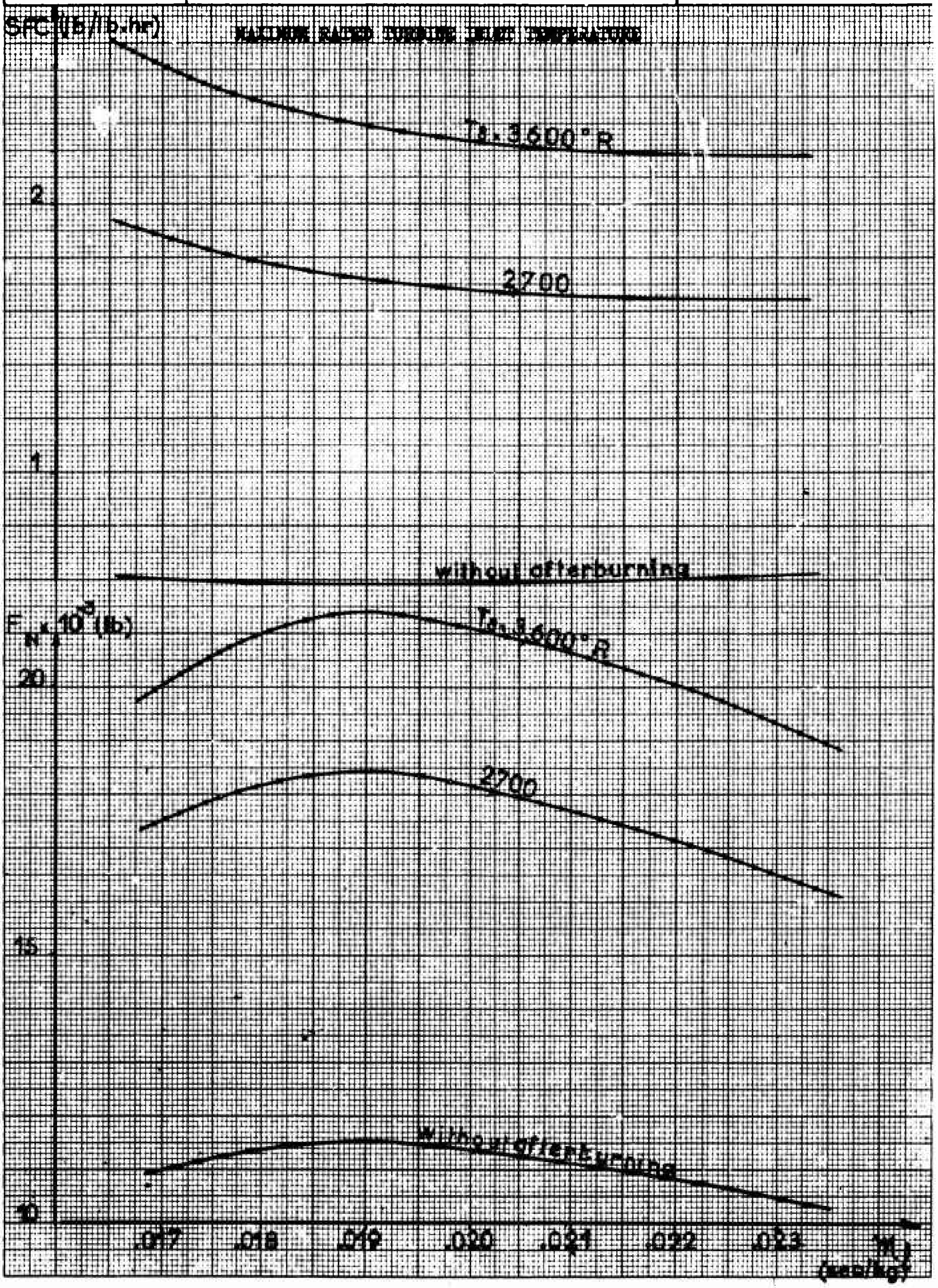
Mach number increases, this rating is more and more reduced, the turbofan is windmilled or even stopped. The operation in pure ramjet configuration is then utilized up to $M_0 = 4$. The variation in the sectional area of the flow stream tube A_0 is low, as it can be seen in Fig.125, and, consequently, the air inlet control during transition is easily effected.

Unfortunately we were not in a position to carry out any accurate calculation relating to the TFR-R transitional range, for this would have required the knowledge of networks showing the turbofan thermodynamic characteristics at temperatures exceeding 550 °K = 990 °R.

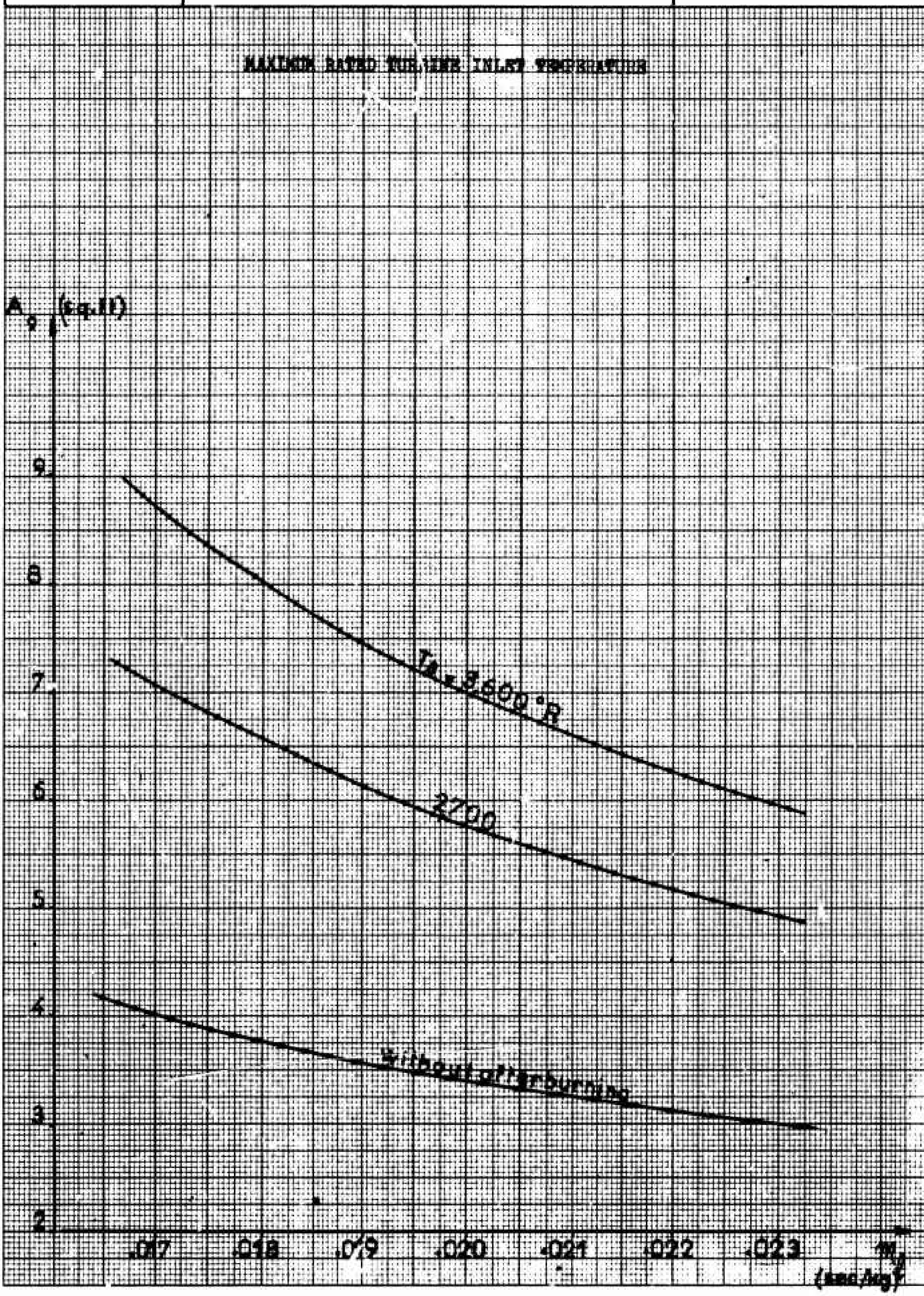
5-3 Performance characteristics evolution in terms of Mach number

Finally, in Fig.124, we have shown the variation of the thrust coefficient in terms of the Mach number at an altitude Z comprised between 36,000 ft and 82,000 ft, in both cases : T_8 = 2,700 °R and T_8 = 3,600 °R. This result sums up all the performance characteristics graph systems previously produced.

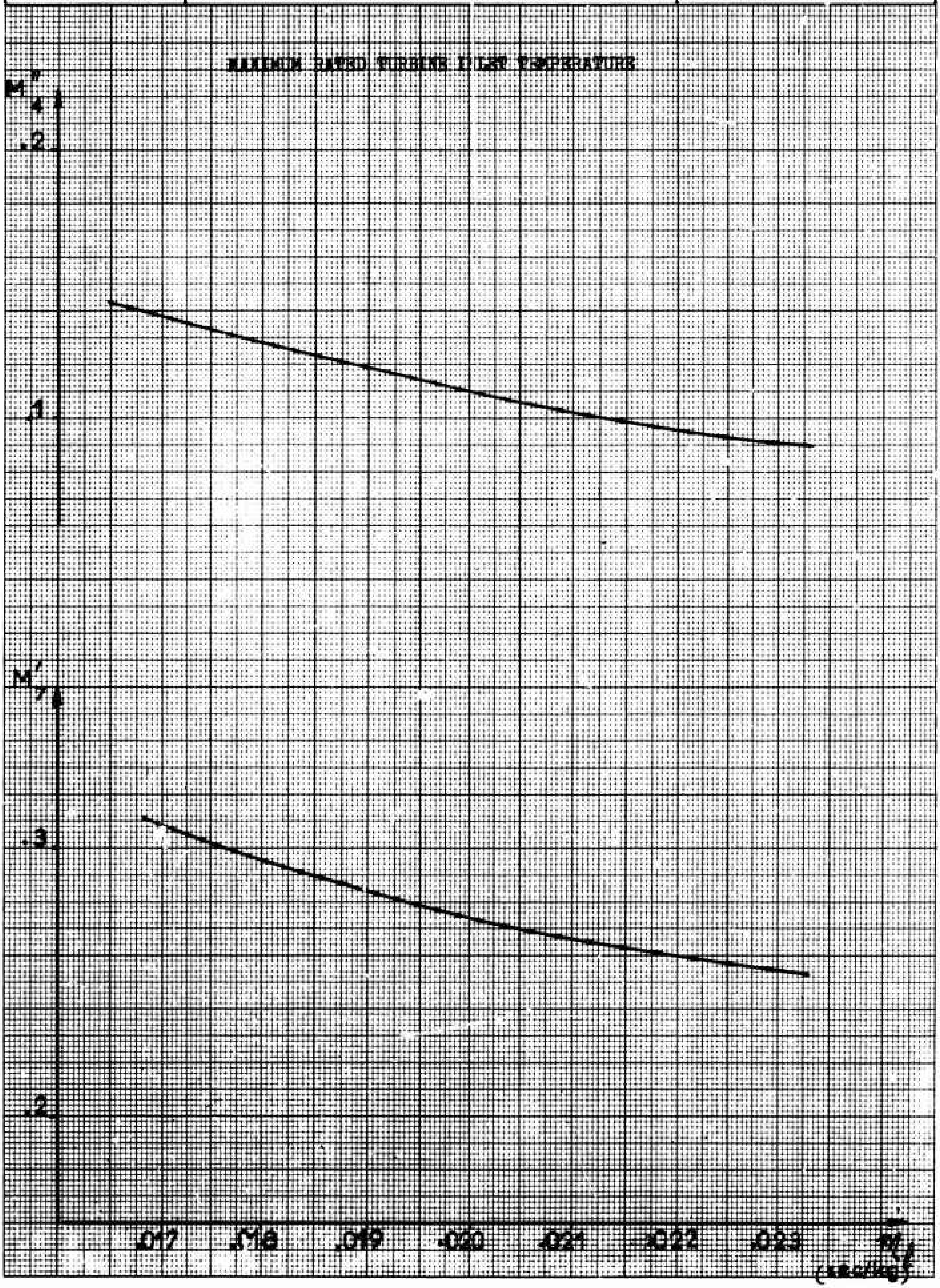
Nord-Aviation	TURBOFAN OPERATION Mo = 0 Z = 0	5152/NIOBE IV/34/Z Figure 1



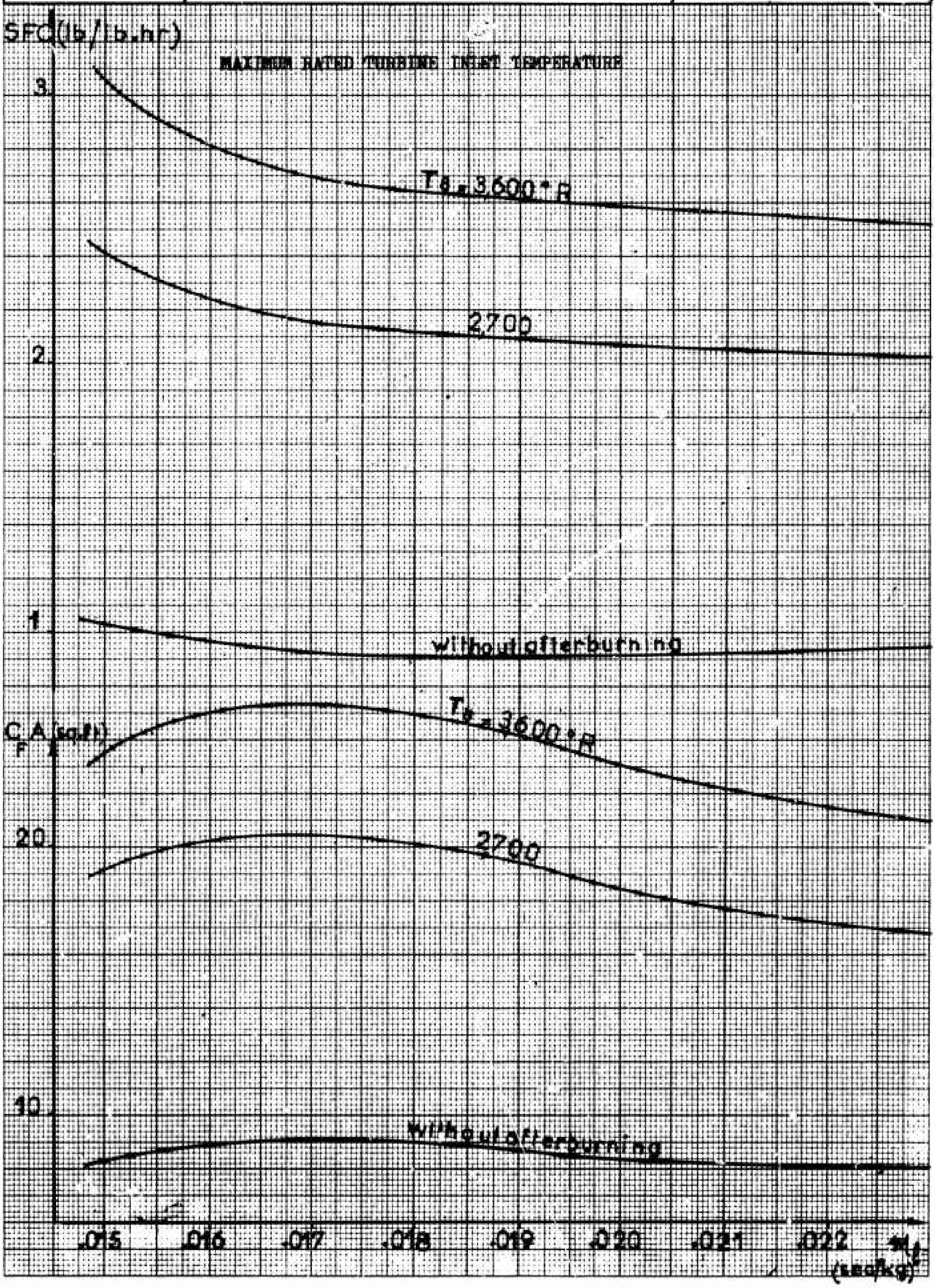
Nord-Aviation	TURBOFAN OPERATION Mo = 0 Z = 0	5152/NIOBE IV/34/Z Figure 2



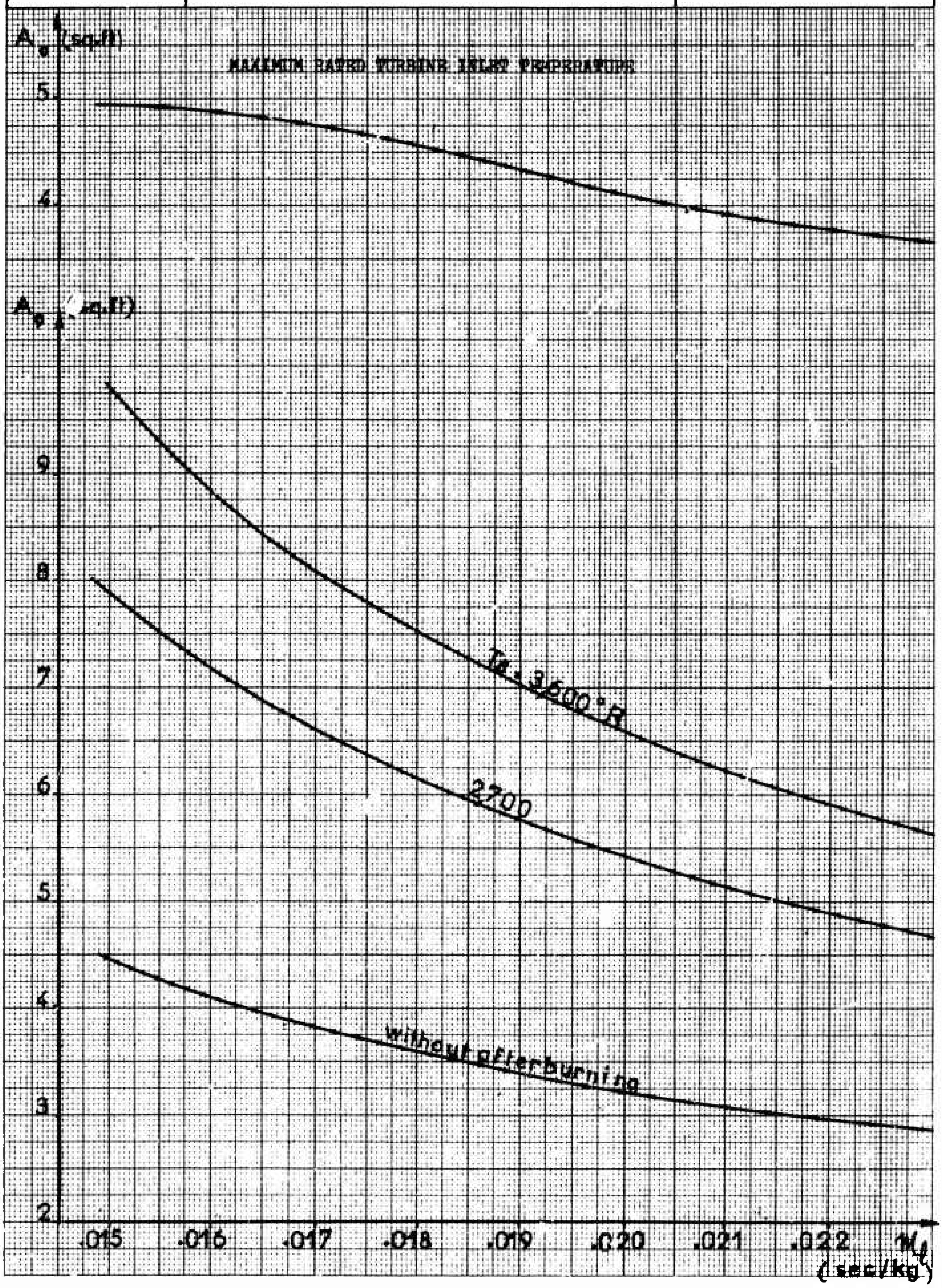
Nord-Aviation	TURBOFAN OPERATION Mo = 0 Z = 0	5152/NIOBE IV/34/Z Figure 3



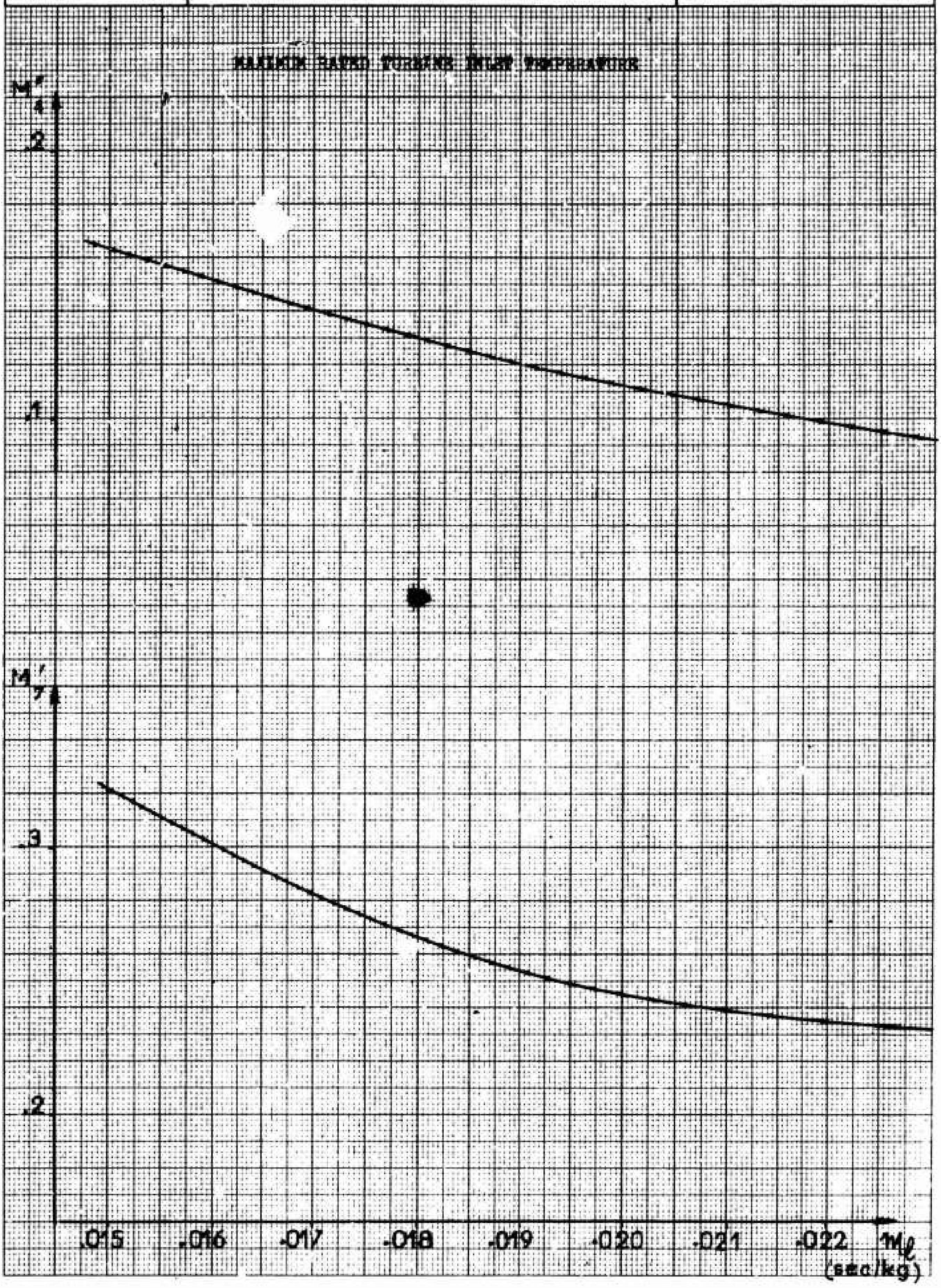
Nord-Aviation	TURBOFAN OPERATION Mo = 0.79 Z = 0	5152/N1OBE IV/34/Z Figure 4



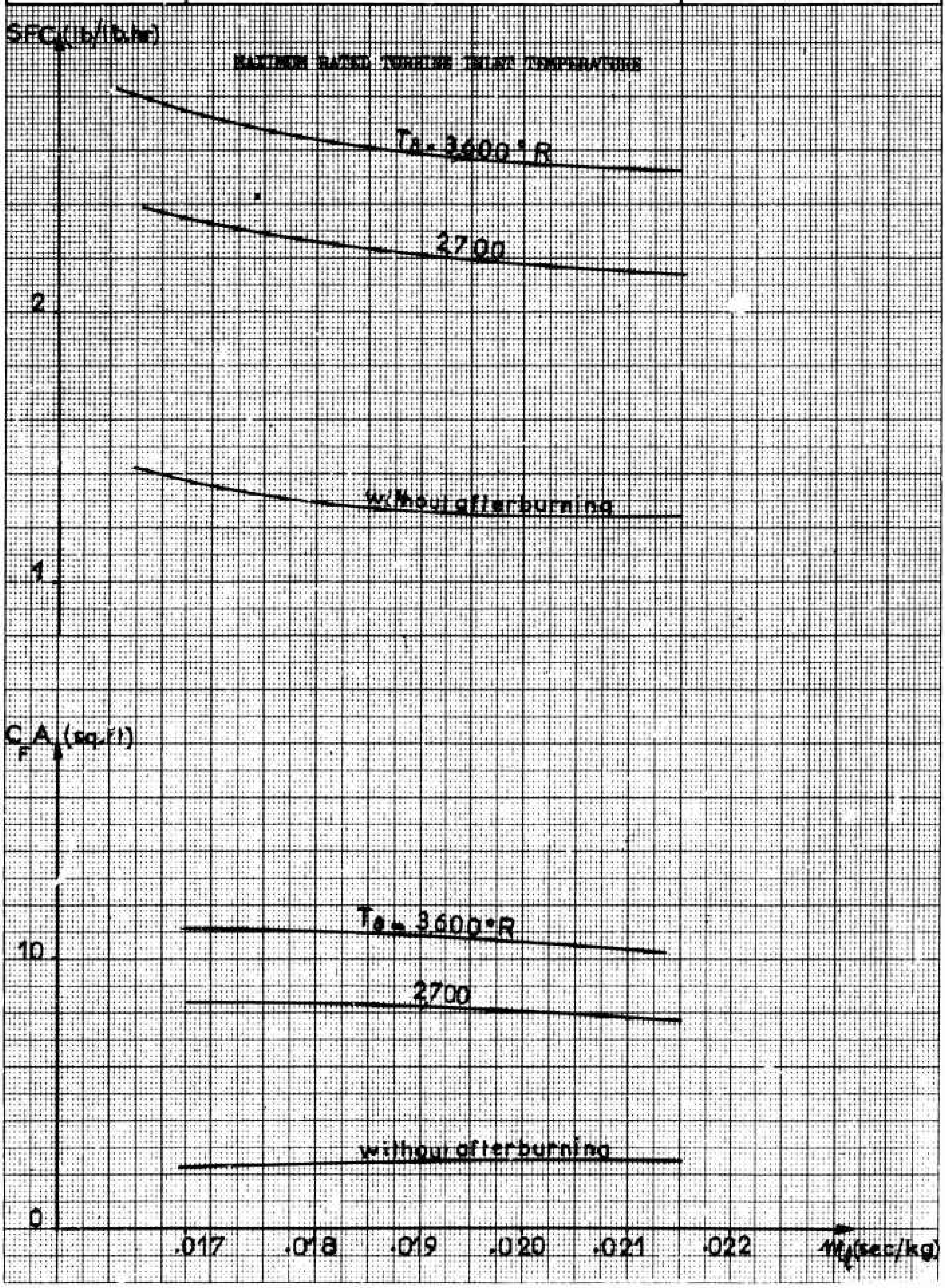
Nord-Aviation	TURBOFAN OPERATION Mo = 0.79 Z = 0	5152/NIOBE IV/34/Z Figure 5



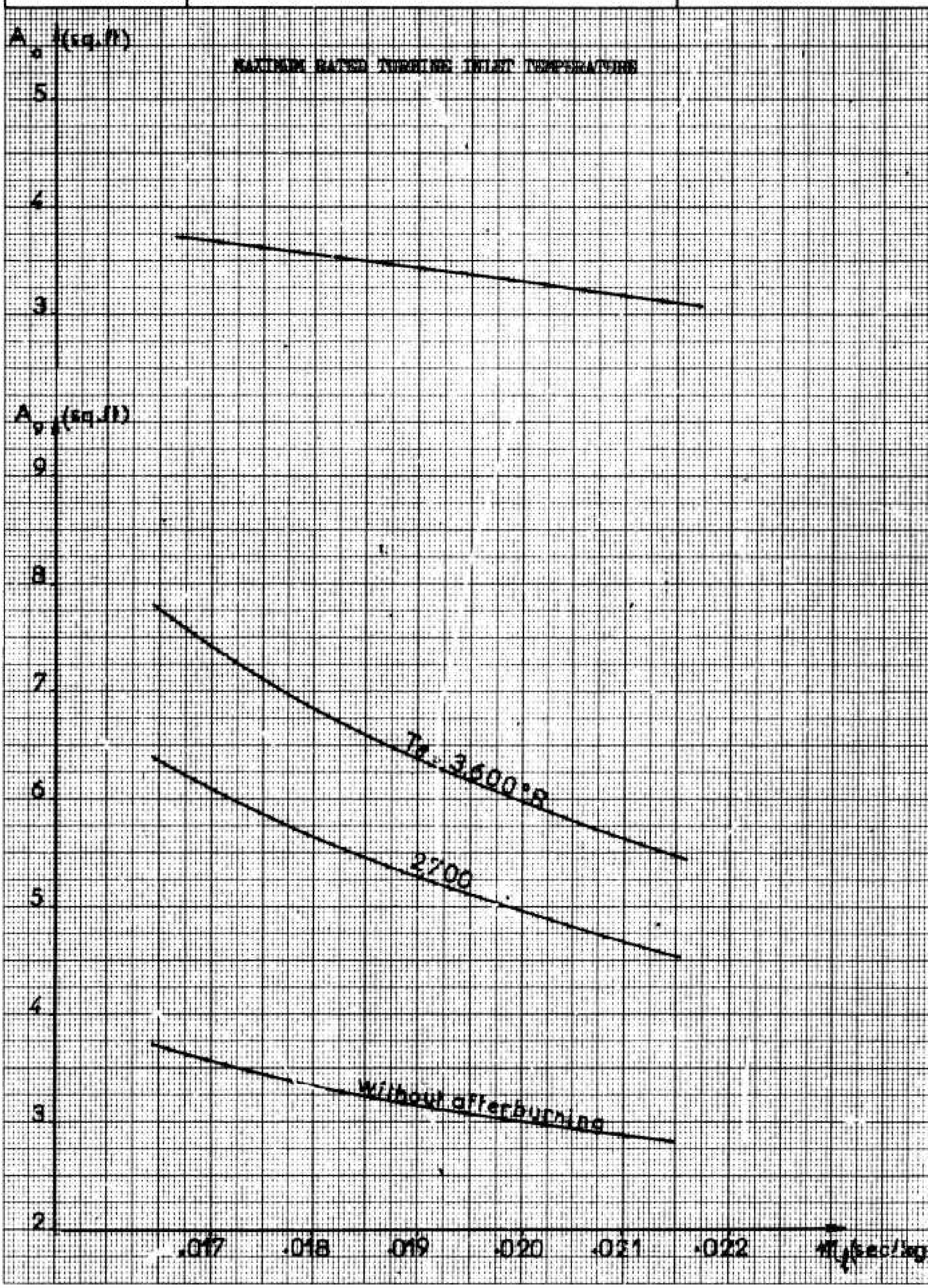
Nord-Aviation	TURBOFAN OPERATION Mo = 0.79 Z = 0	5152/NIOBE IV/34/Z Figure 6



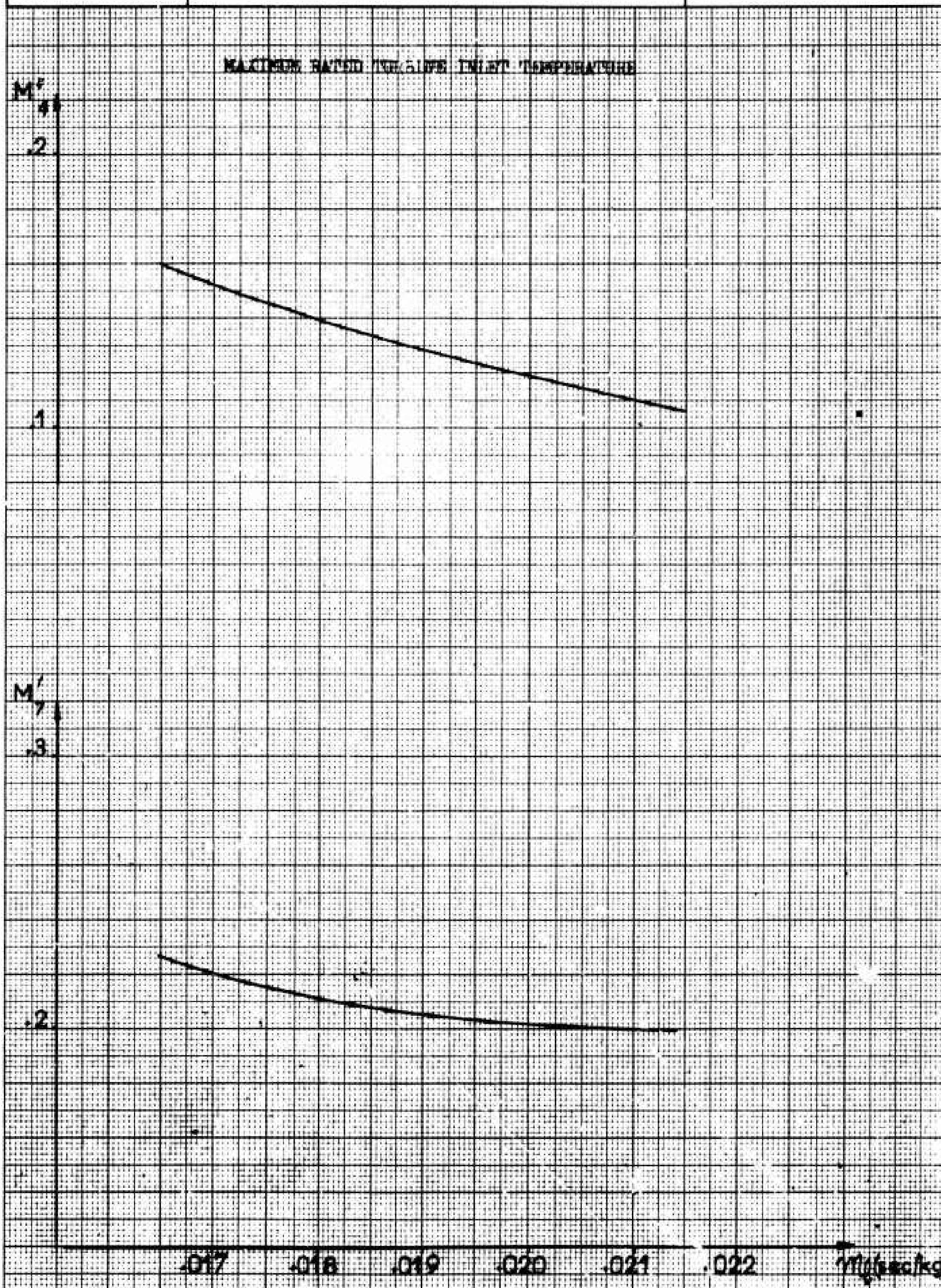
Nord-Aviation	TURBOFAN OPERATION Mo = 1.33 Z = 0	5152/NIOBE IV/34/Z Figure 7



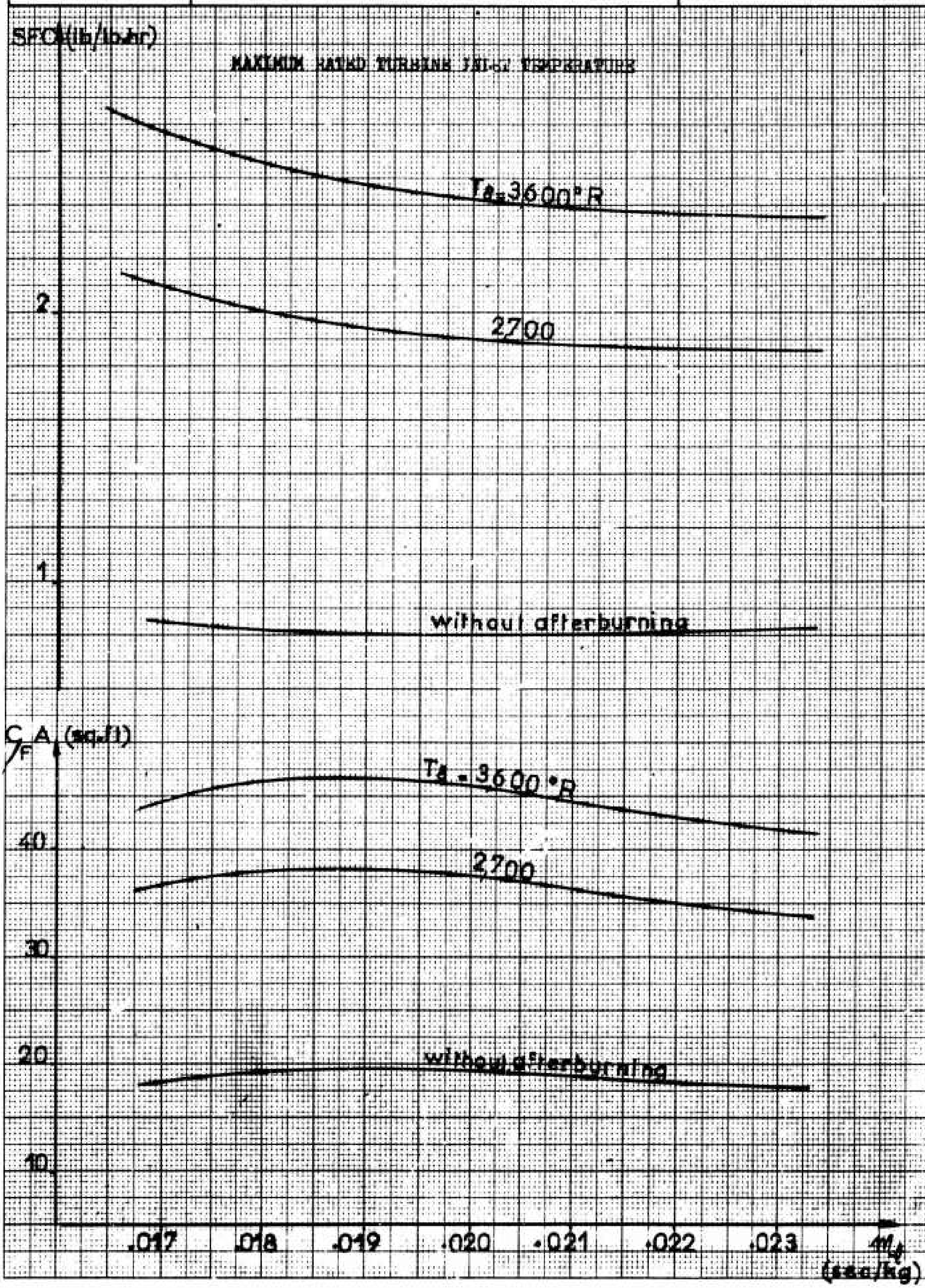
Nord-Aviation	TURBOFAN OPERATION Mo = 1.33 Z = 0	5152/NIOBE IV/34/Z Figure 8



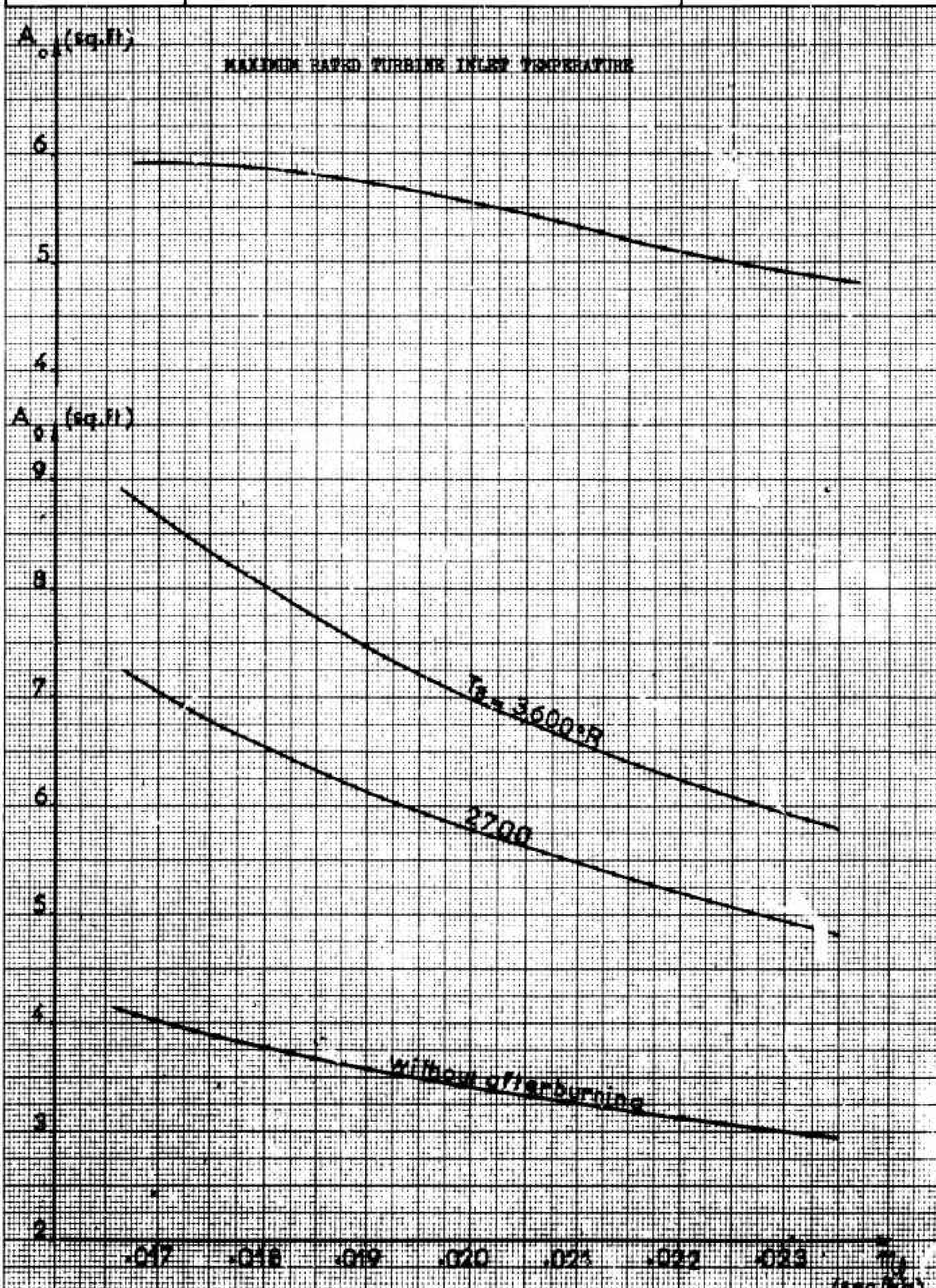
Nord-Aviation	TURBOFAN OPERATION Mo = 1.33 Z = 0	5152/NIOBE IV/34/Z Figure 9



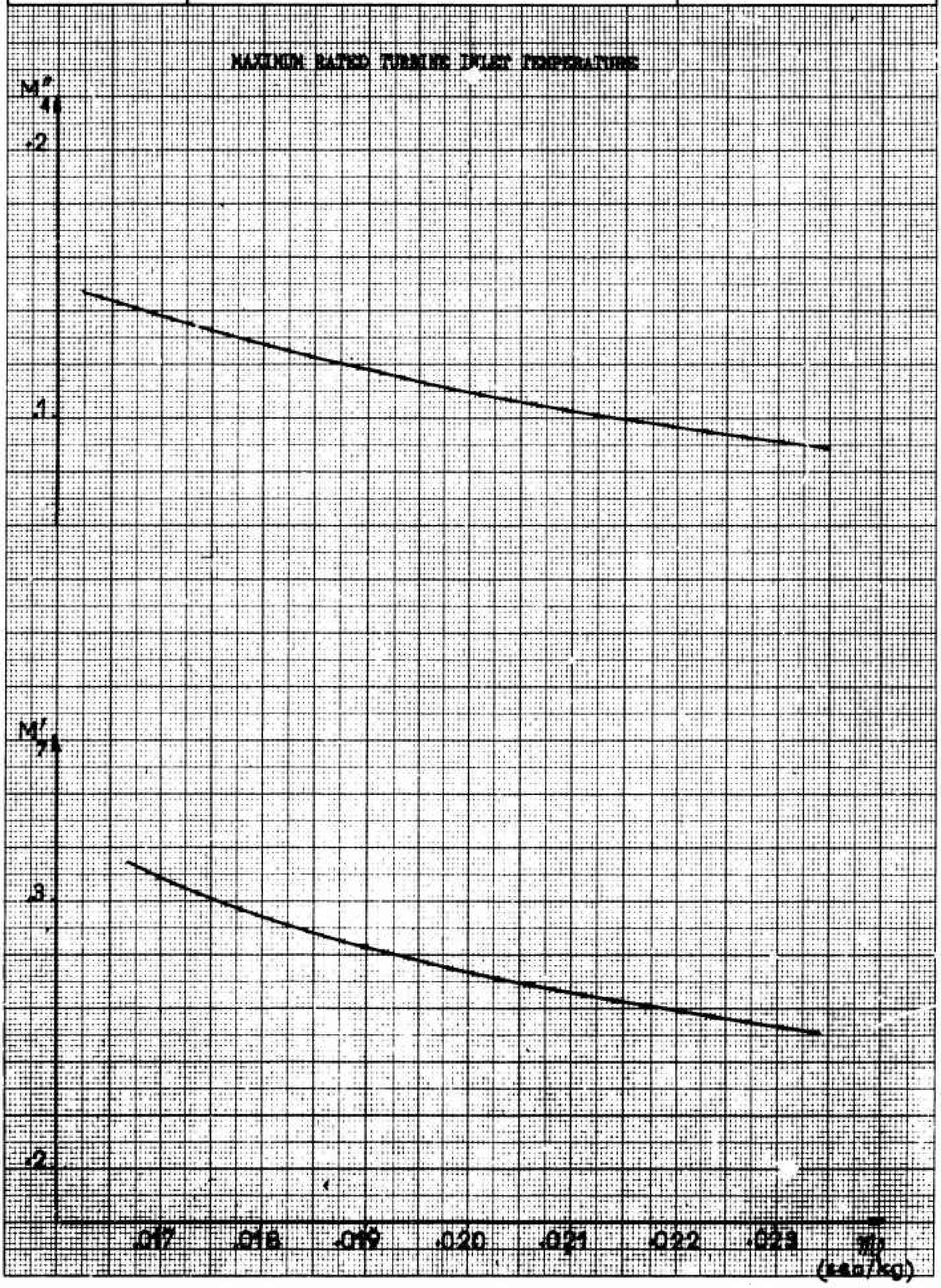
Nord-Aviation	TURBOFAN OPERATION Mo = 0.61 Z = 10 000 ft	5152/NIOBE IV/ 34/Z Figure 10



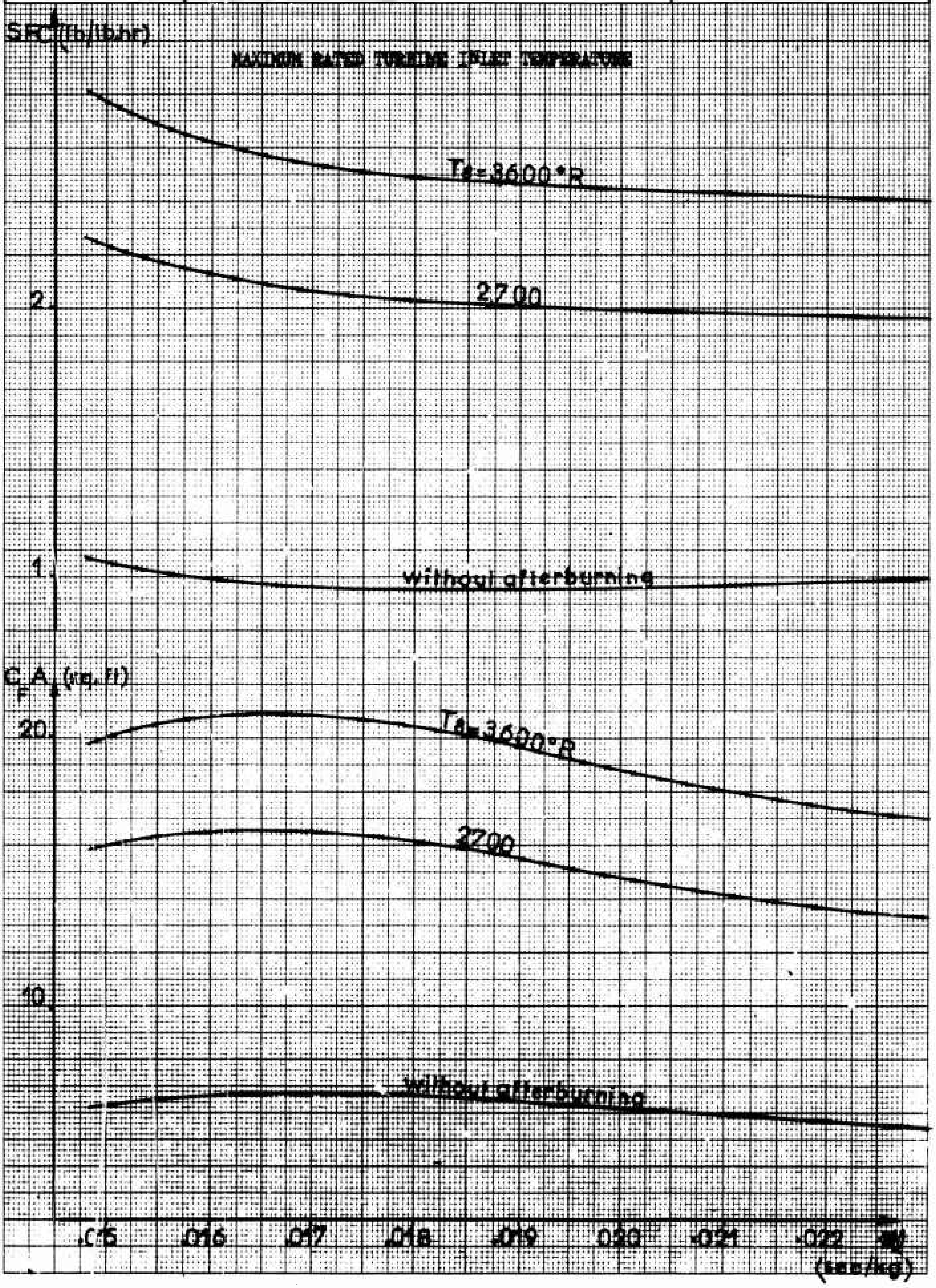
Nord-Aviation	TURBOFAN OPERATION Mo = 0.6? Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 11



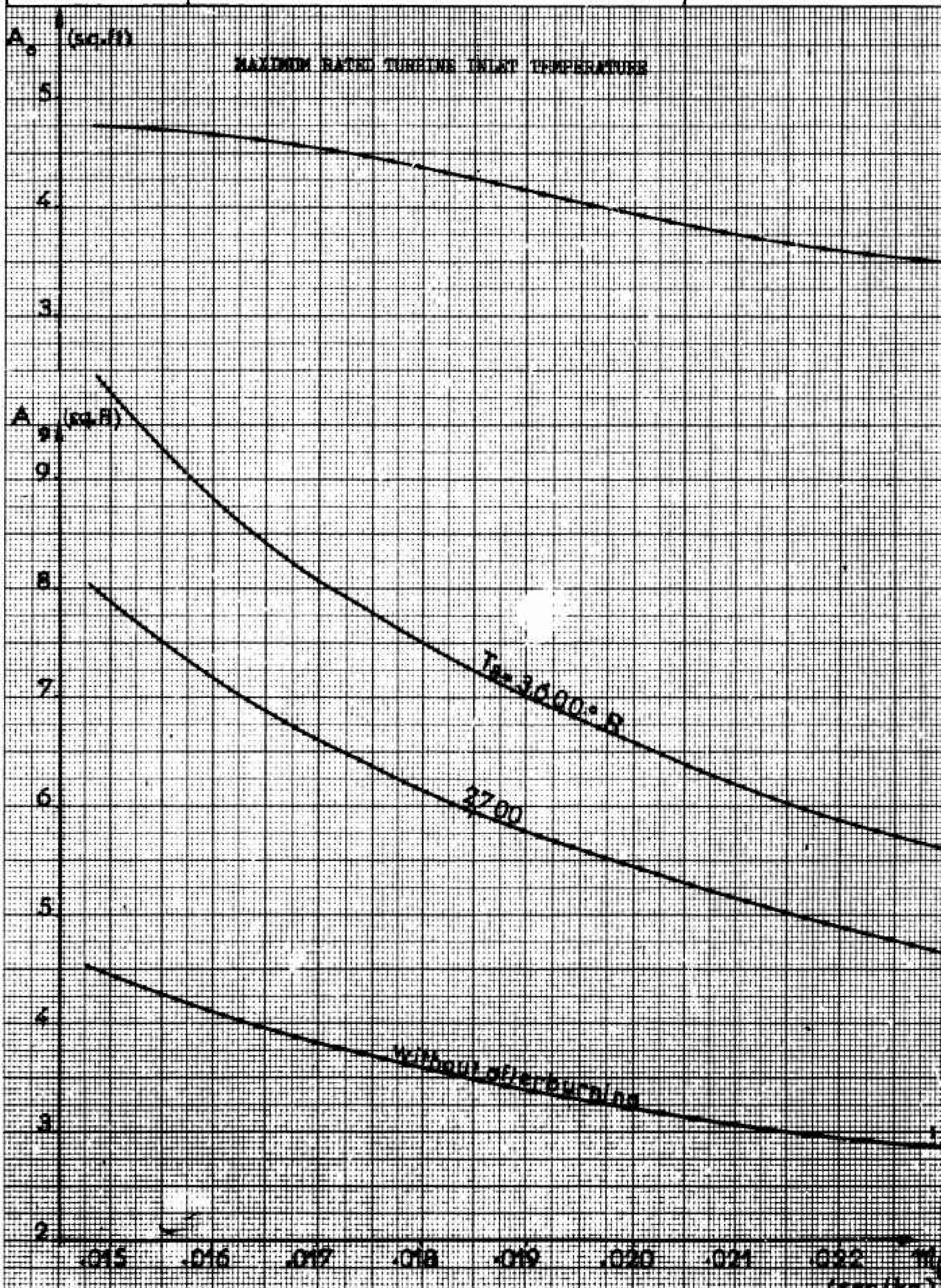
Nord-Aviation	TURBOFAN OPERATION Mo = 0.61 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 12



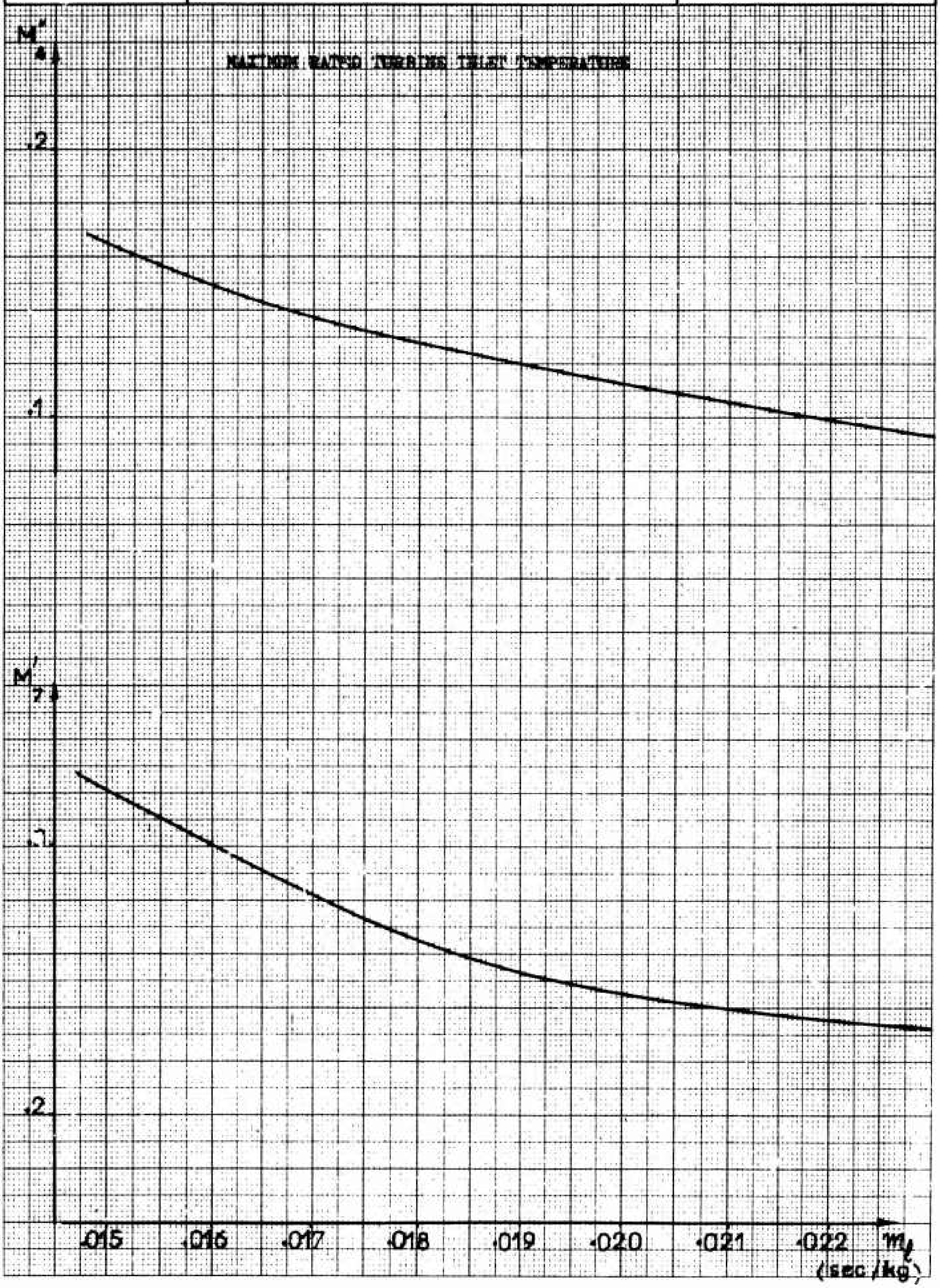
Nord-Aviation	TURBOFAN OPERATION Mo = 1.02 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 13



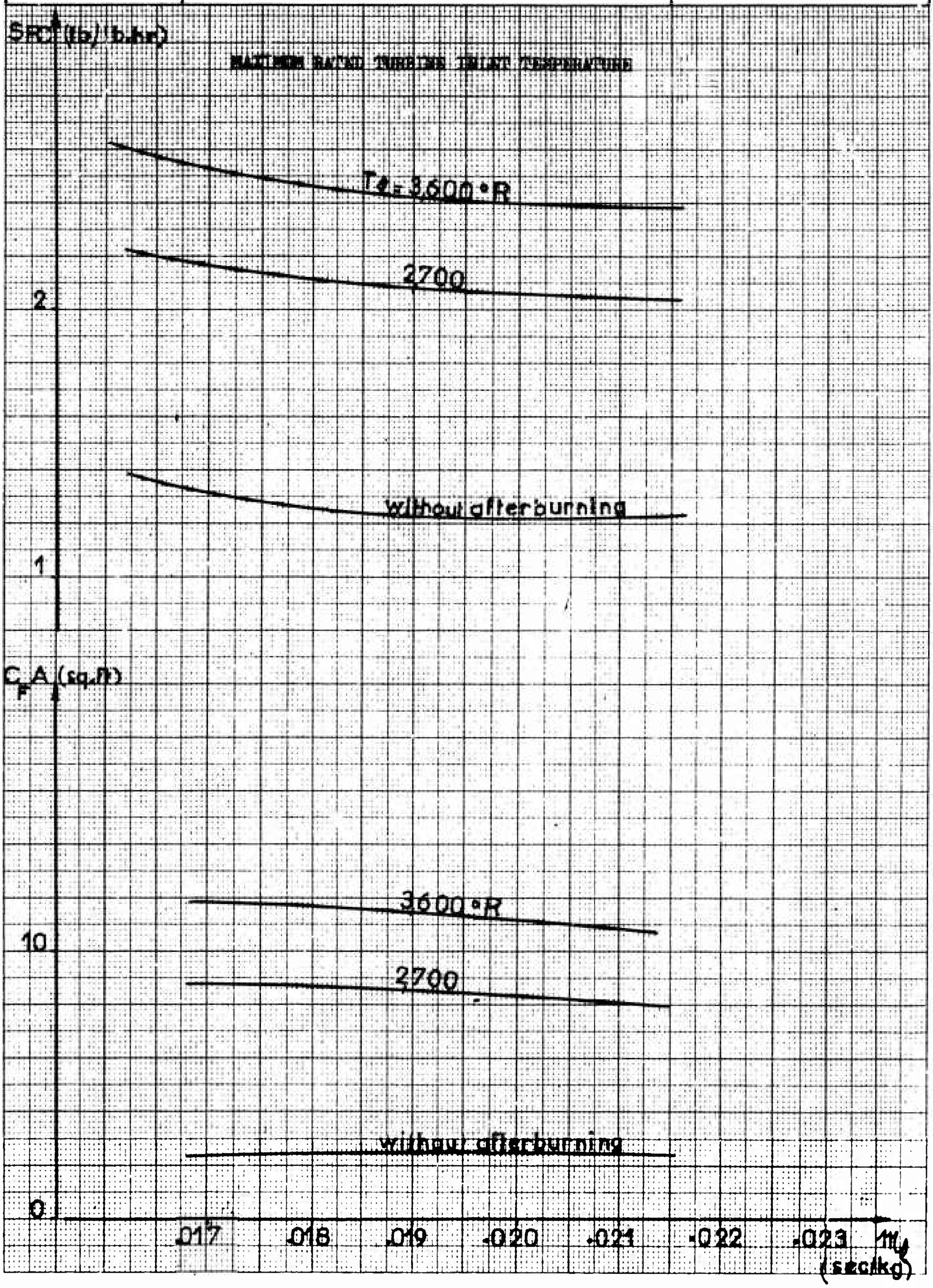
Nord-Aviation	TURBOFAN OPERATION Mo = 1.02 Z = 10 000 ft	5152/NIOBE IV/34/2 Figure 14



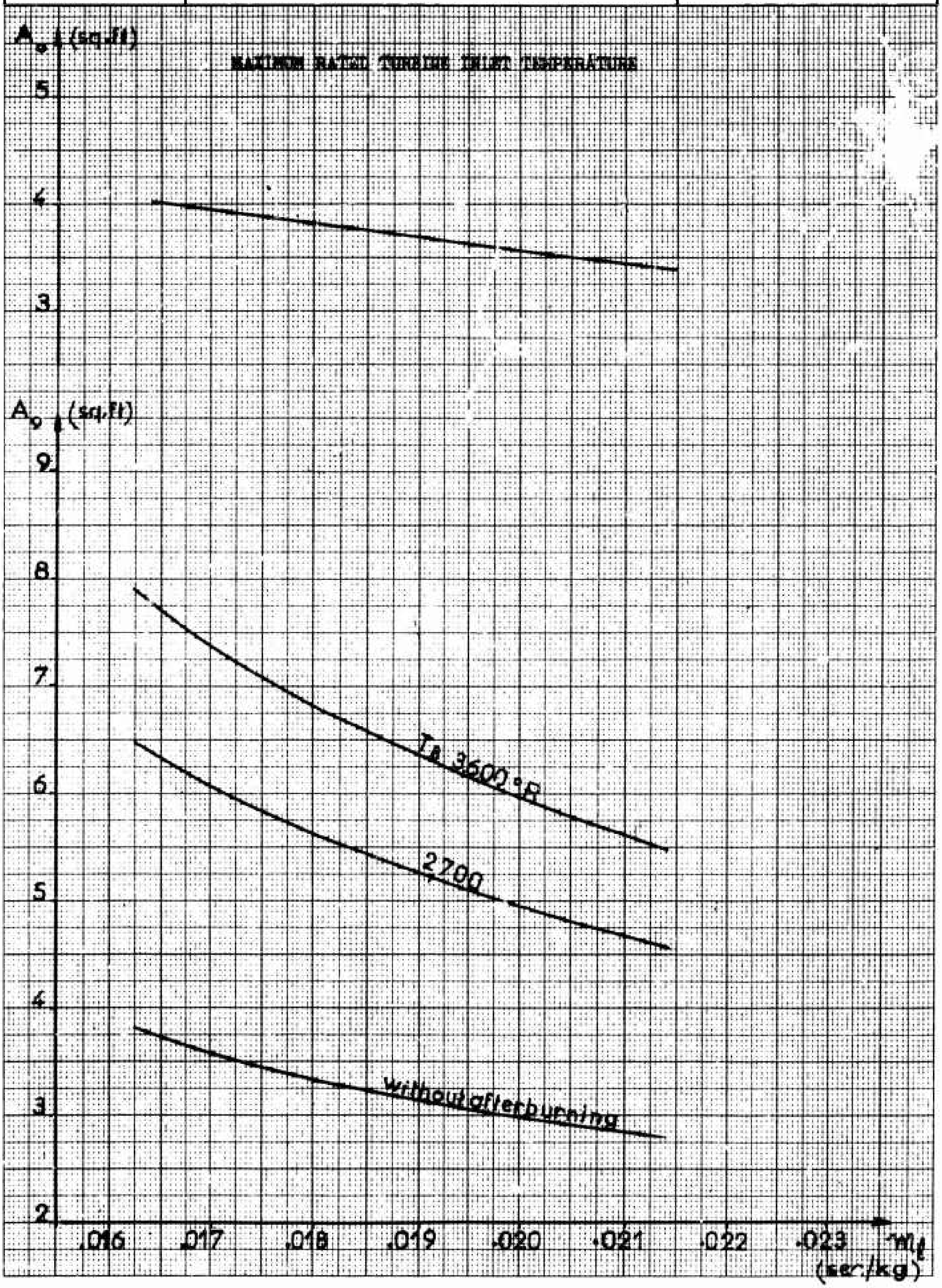
Nord-Aviation	TURBOFAN OPERATION Mo = 1.02 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 15



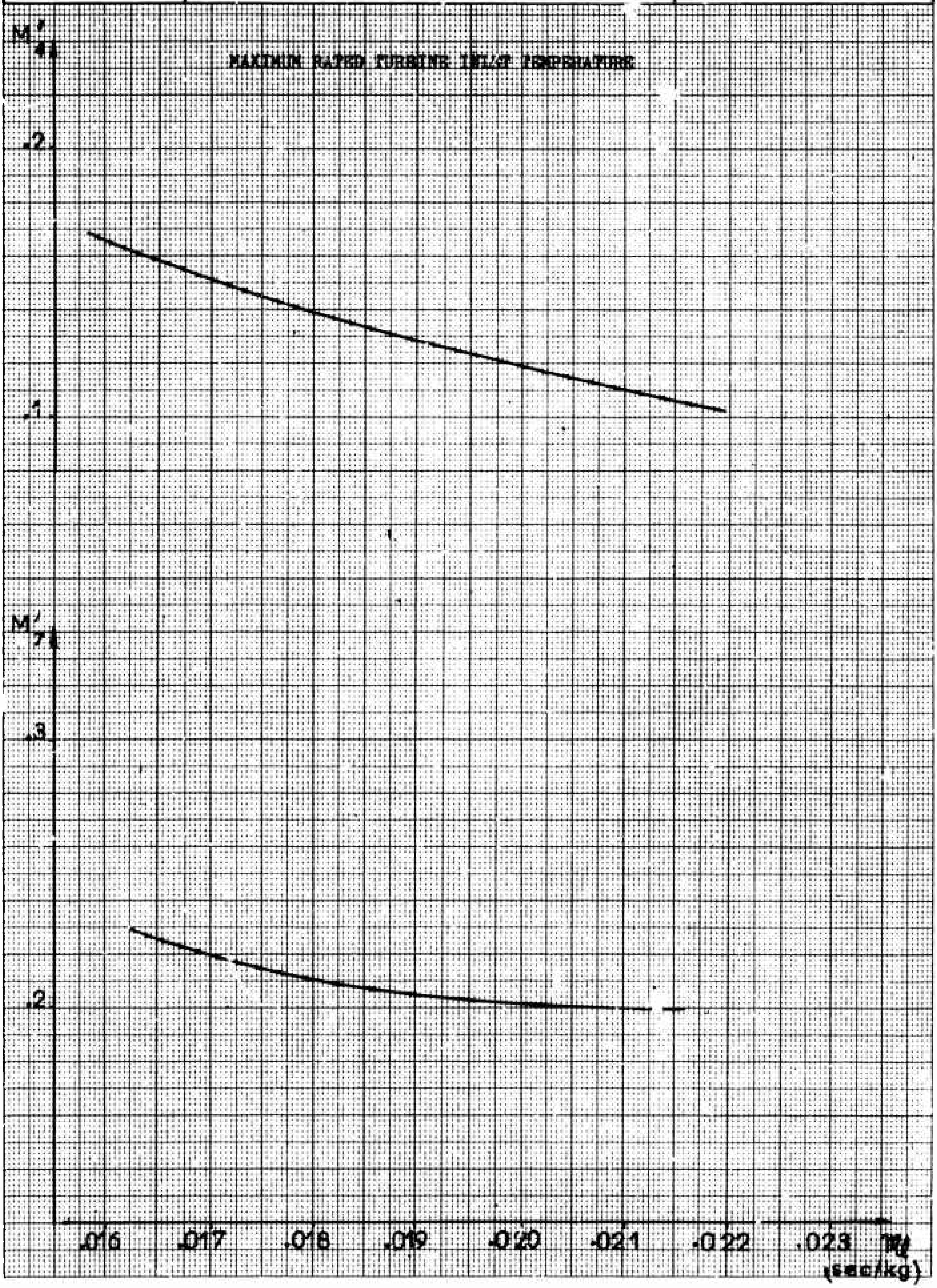
Nord-Aviation	TURBOFAN OPERATION Mo = 1.51 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 16



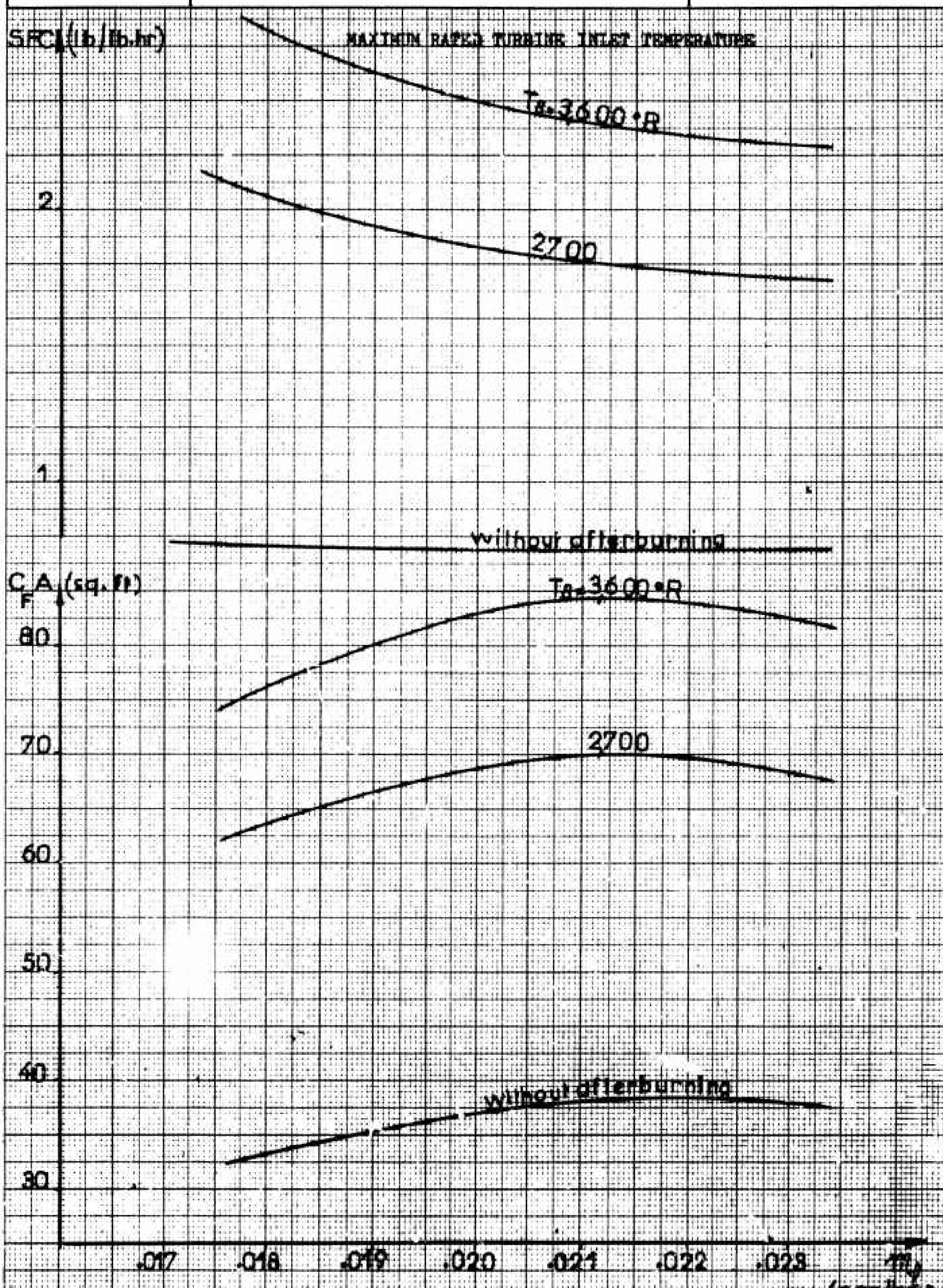
Nord-Aviation	TURBOFAN OPERATION Mo = 1.51 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 17



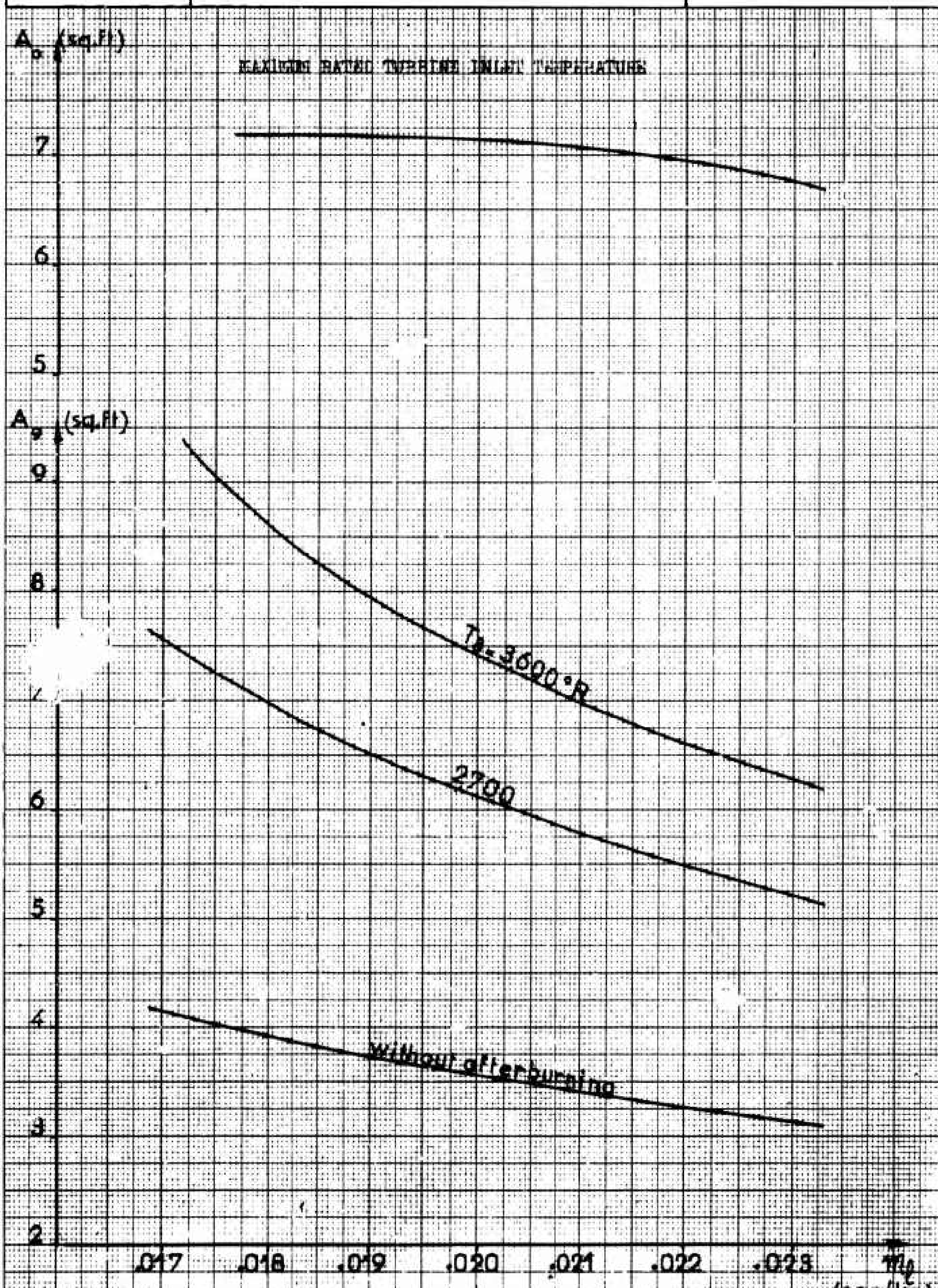
Nord-Aviation	TURBOFAN OPERATION Mo = 1.51 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 18



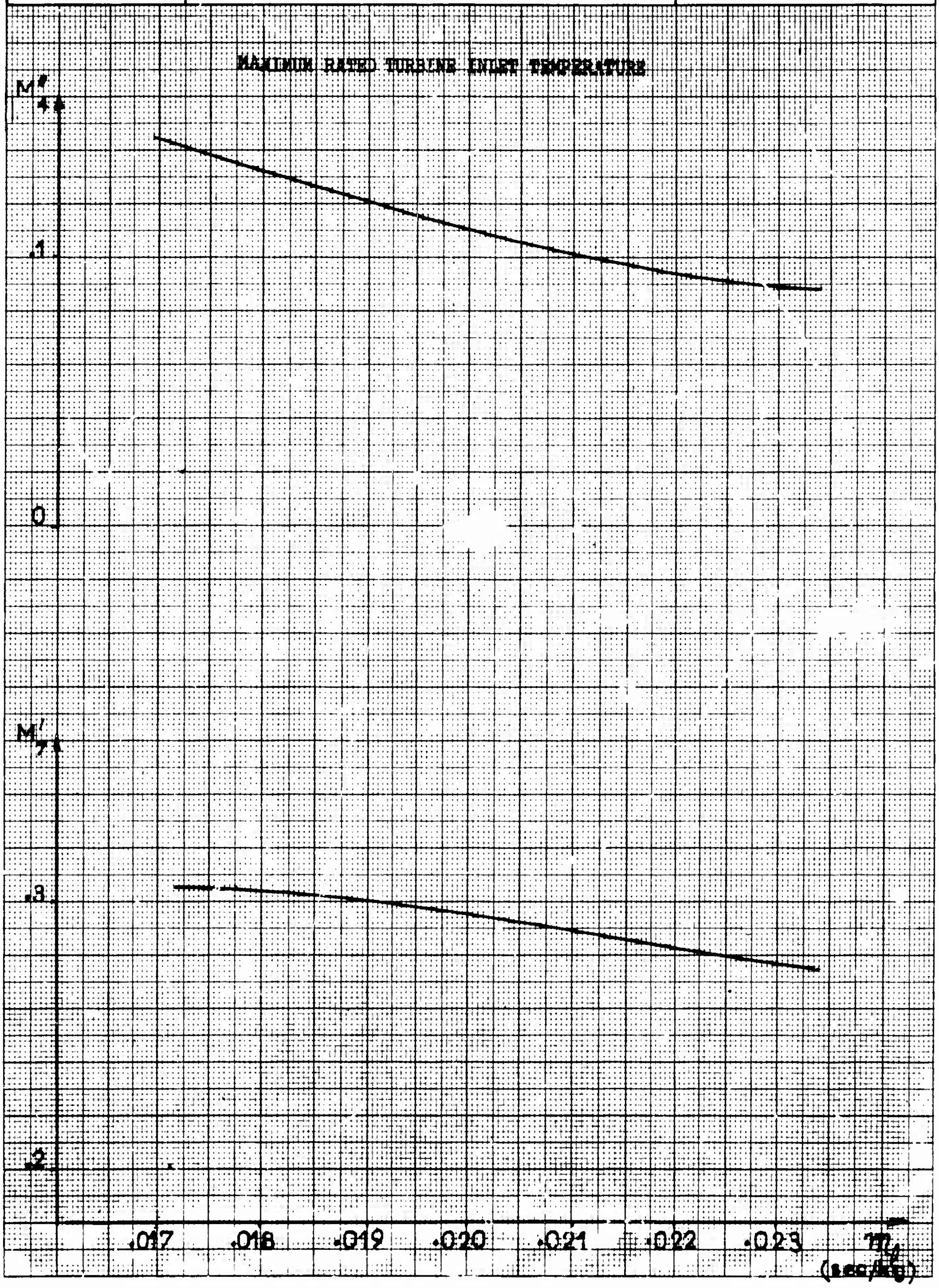
Nord-Aviation	TURBOFAN OPERATION Mo = 0.48 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 19



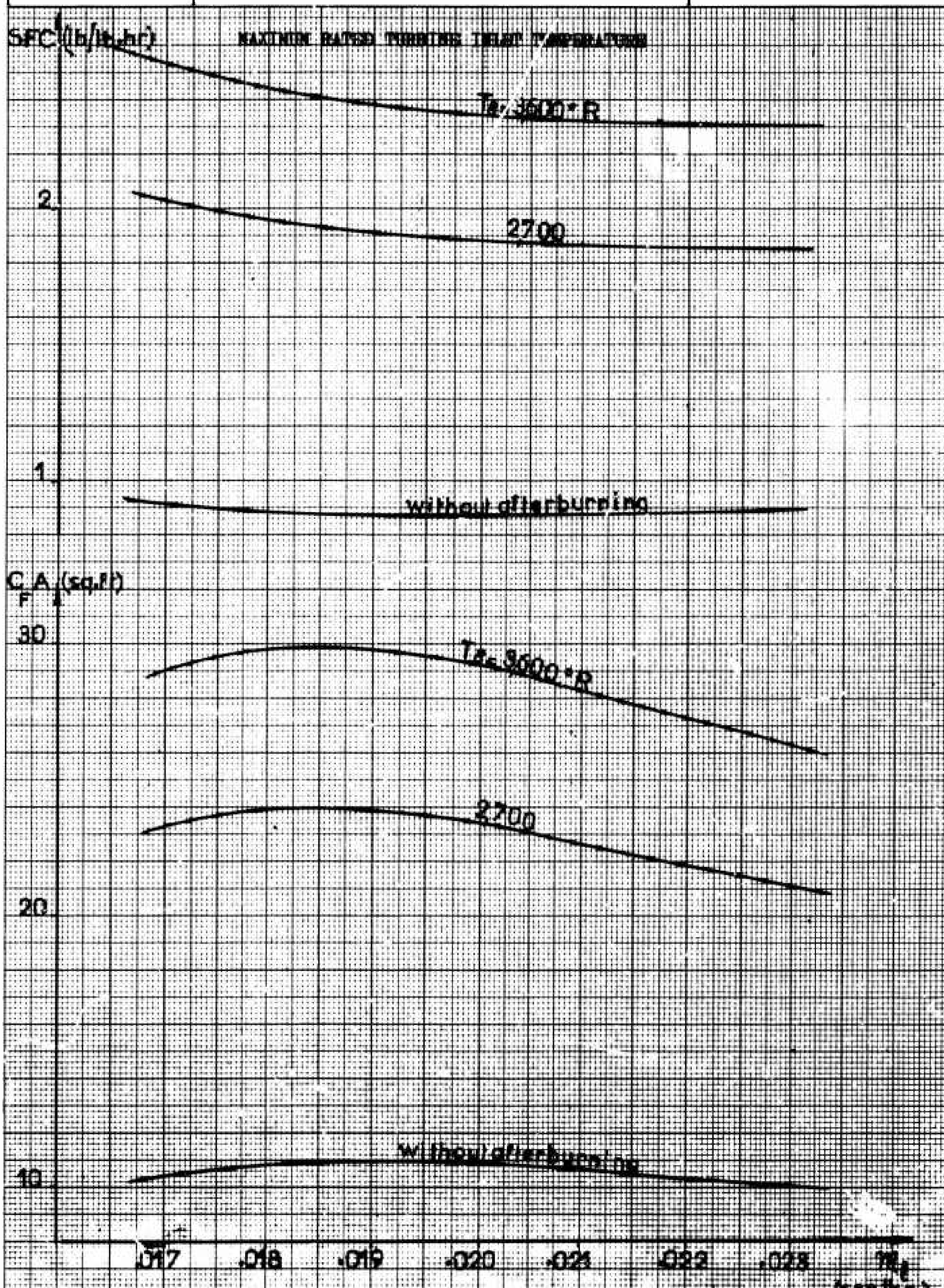
Nord-Aviation	TURBOFAN OPERATION Mo = 0.48 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 20



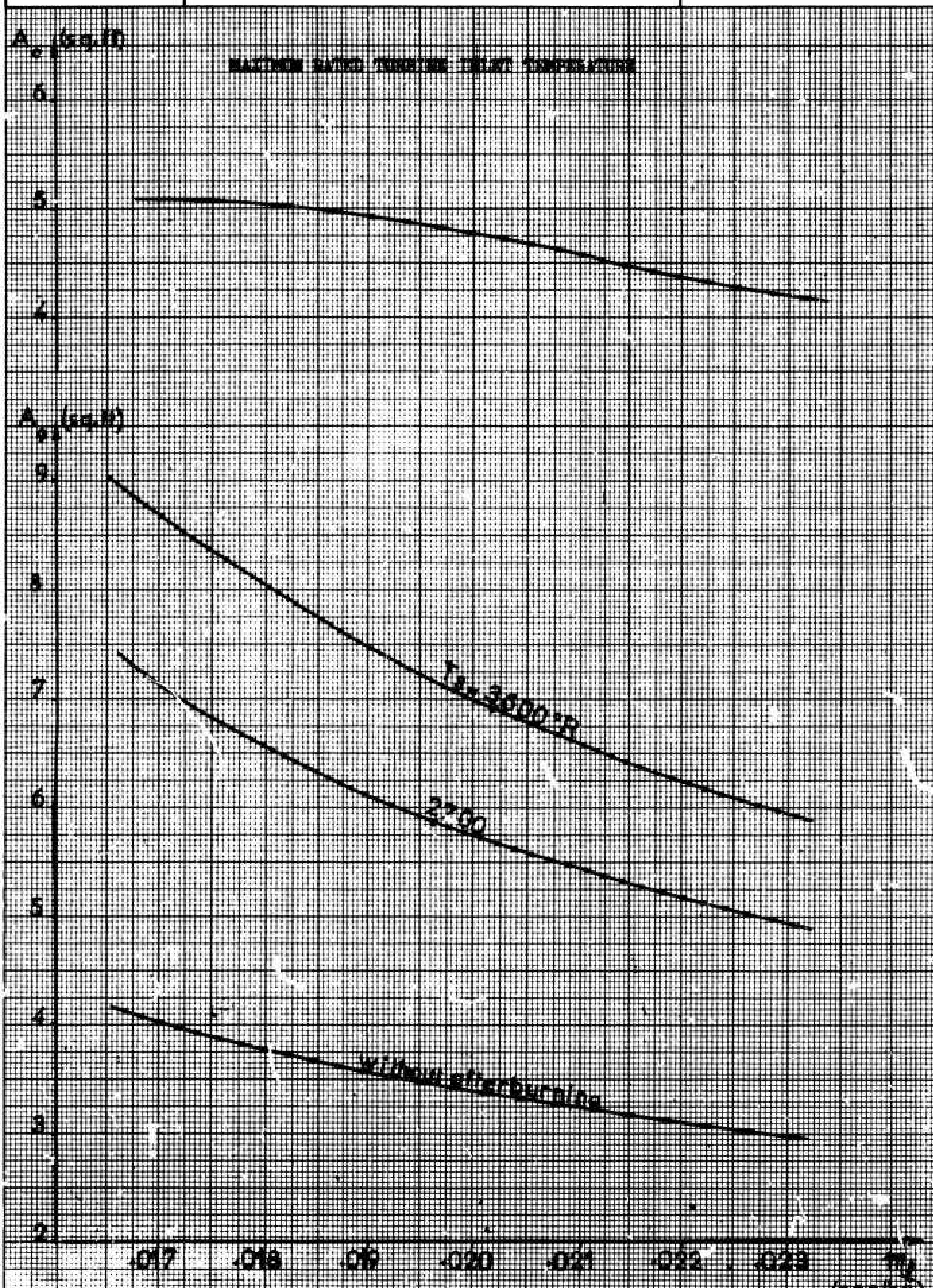
Nord-Aviation	TURBOFAN OPERATION Mo = 0.48 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 21



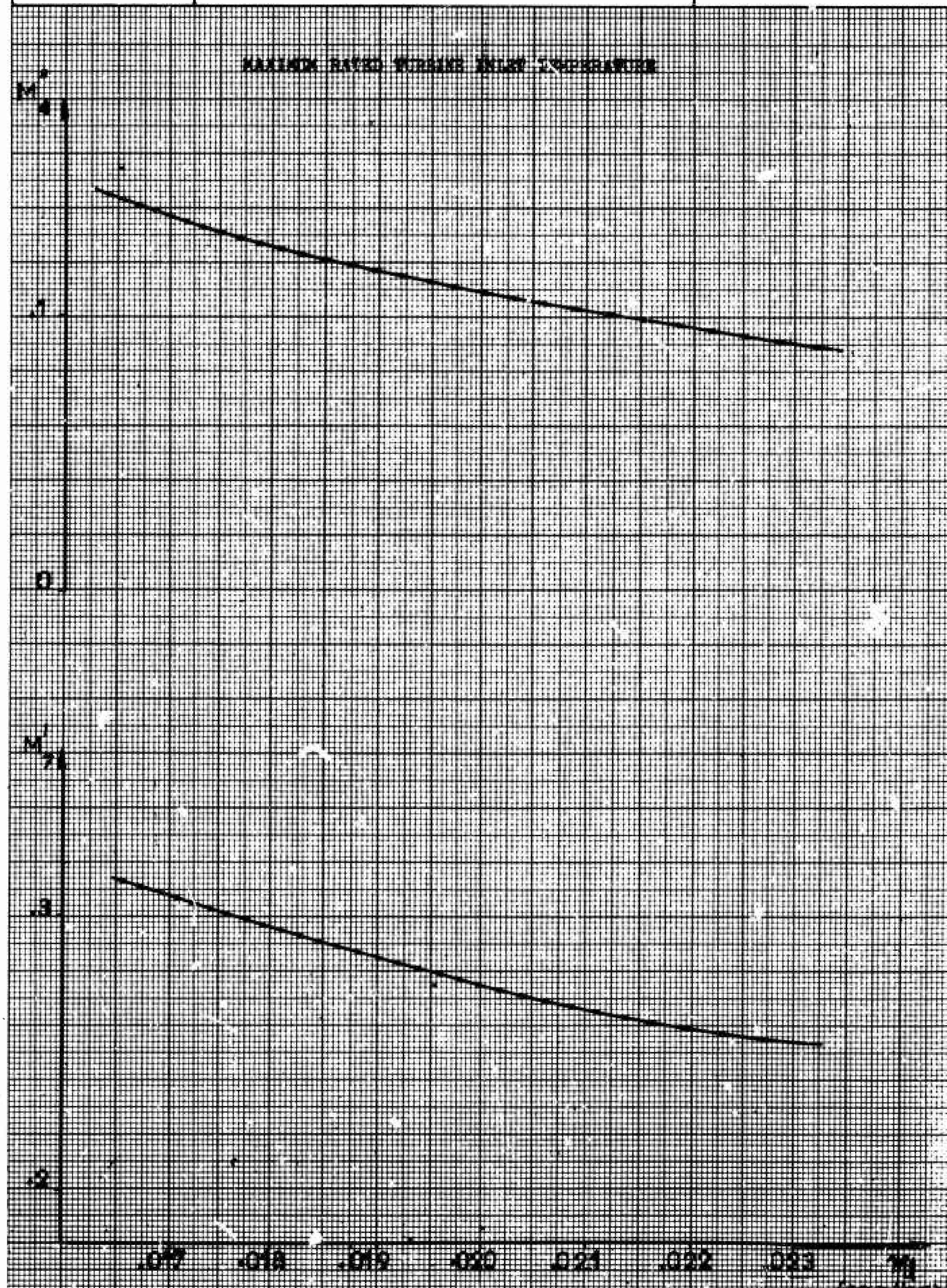
Nord-Aviation	TURBOFAN OPERATION Mo = 0.89 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 22



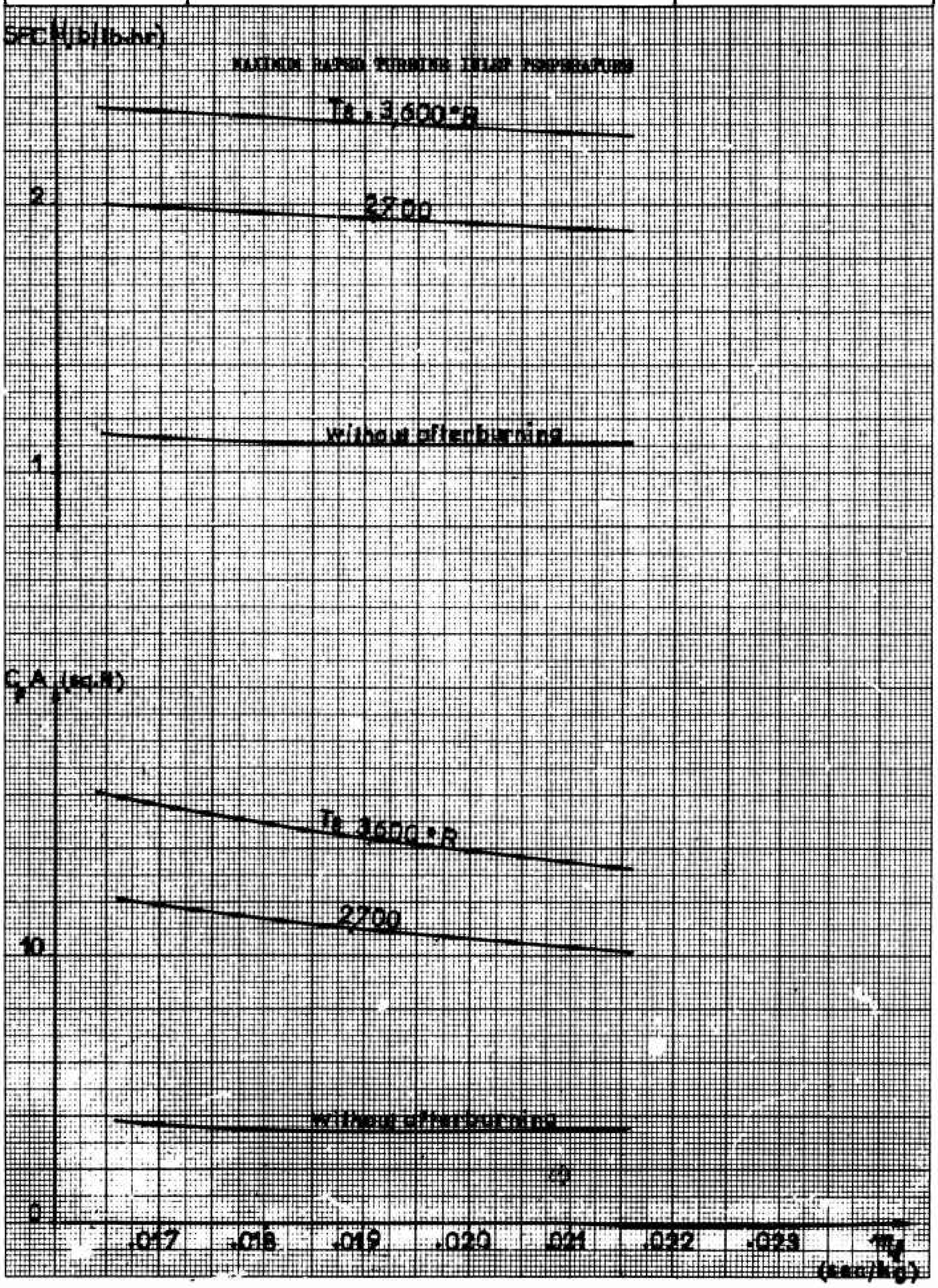
Nord-Aviation	TURBOFAN OPERATION M_0 = 0.85 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 23



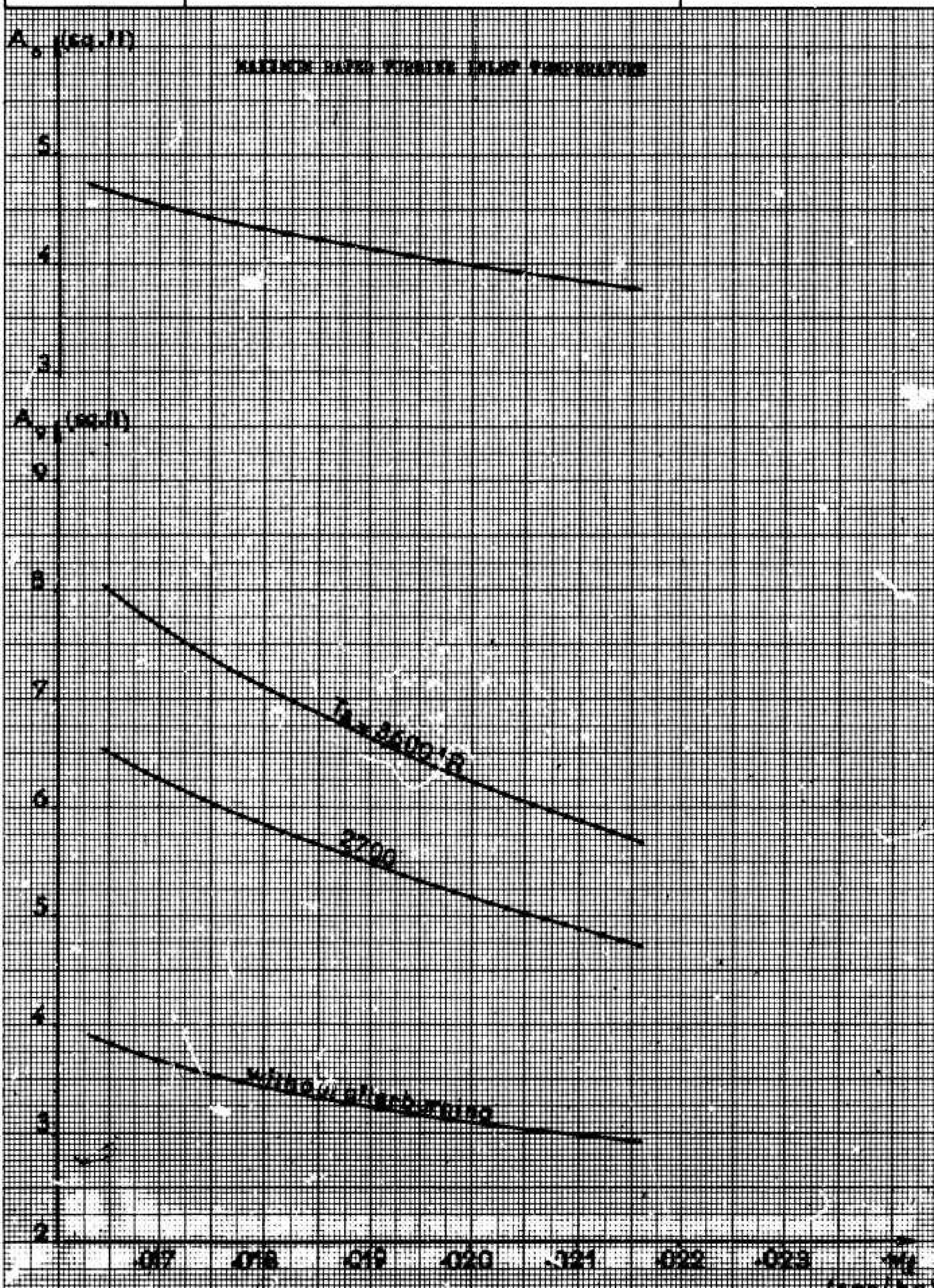
Nord-Aviation	TURBOFAN OPERATION Mo = 0.89 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 24



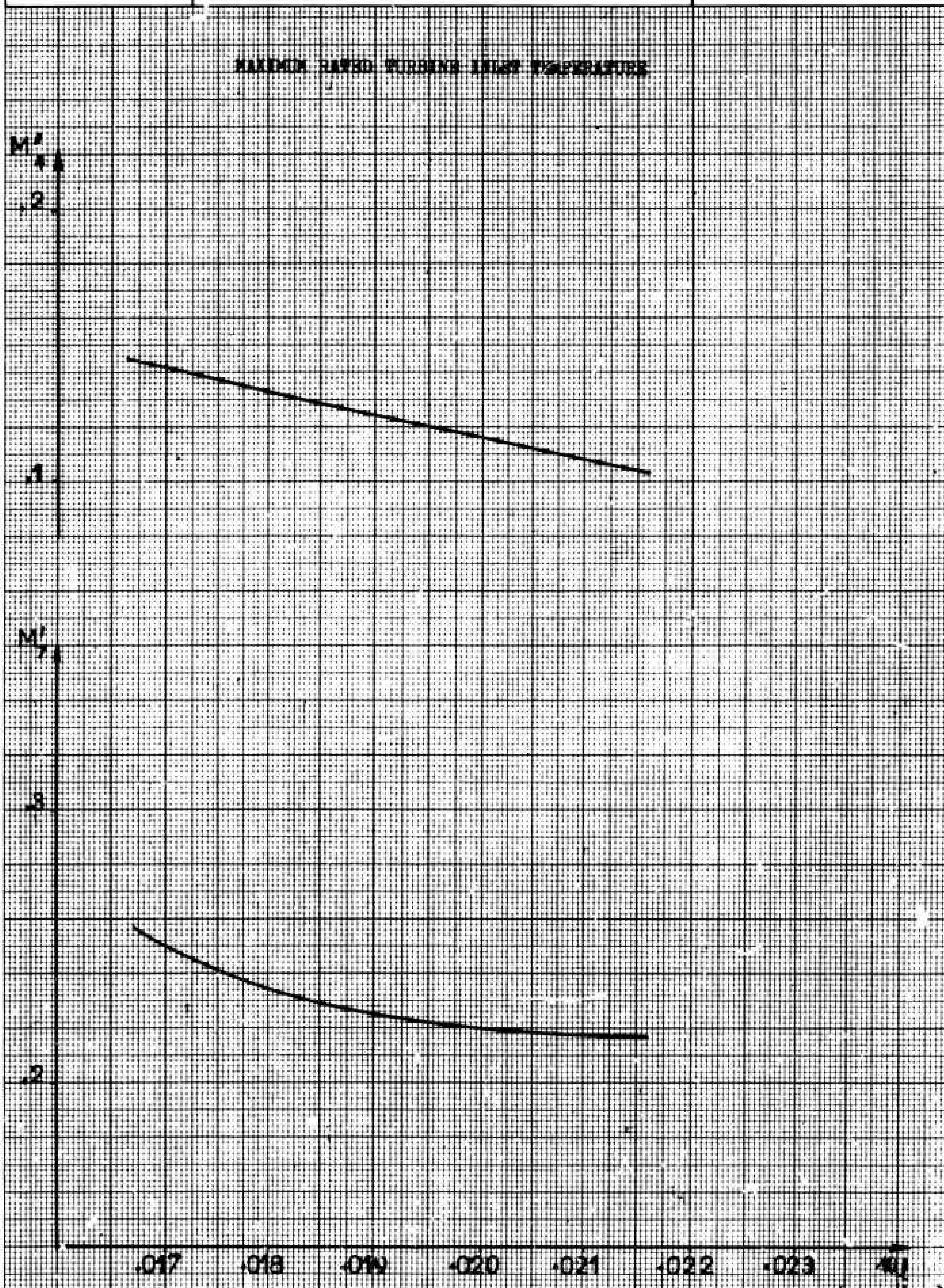
Nord-Aviation	TURBOFAN OPERATION Mo = 1.50 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 25



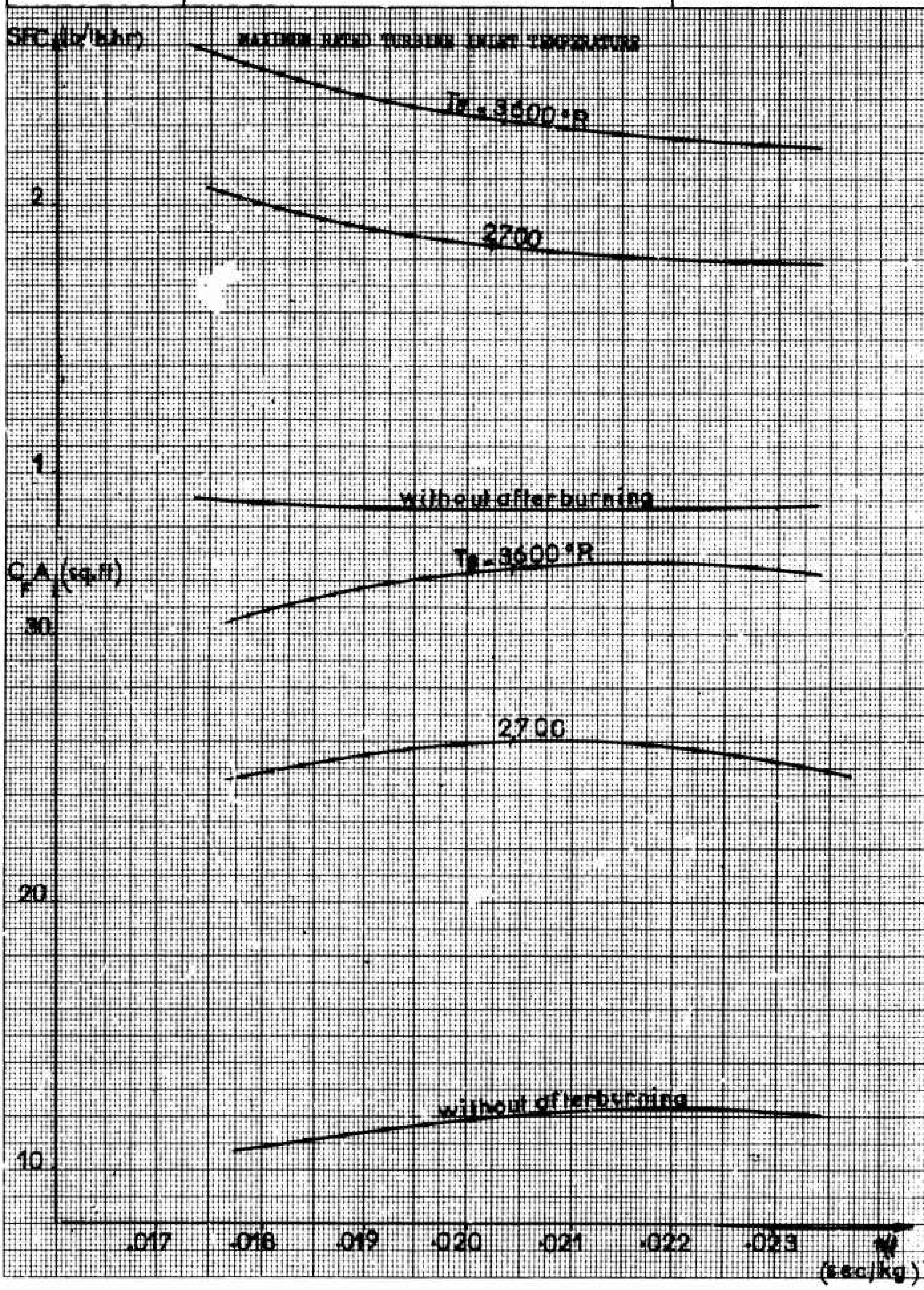
Nord-Aviation	TURBOFAN OPERATION Mo = 1.50 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 26



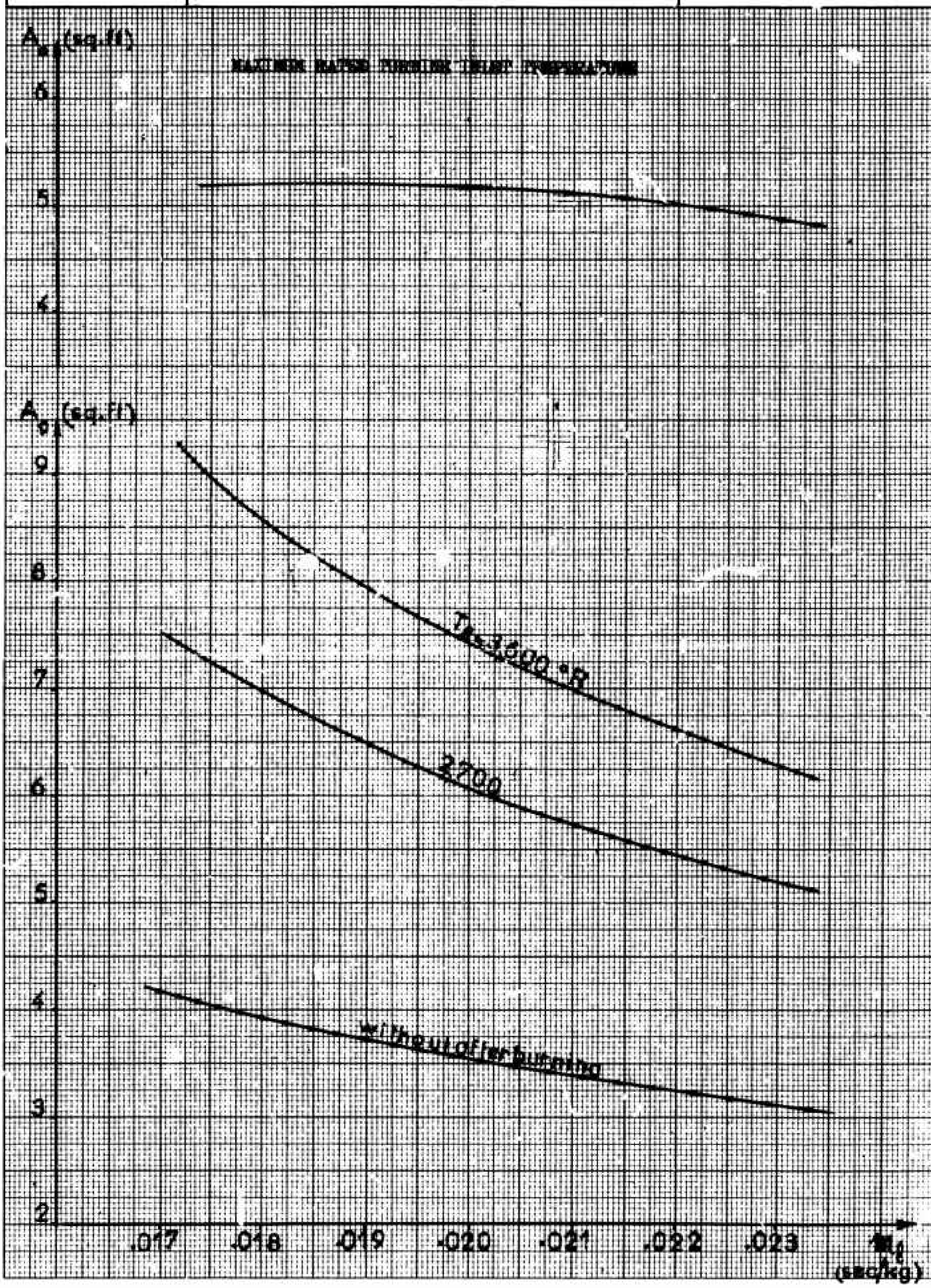
Nord-Aviation	TURBOFAN OPERATION Mo = 1.50 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 27



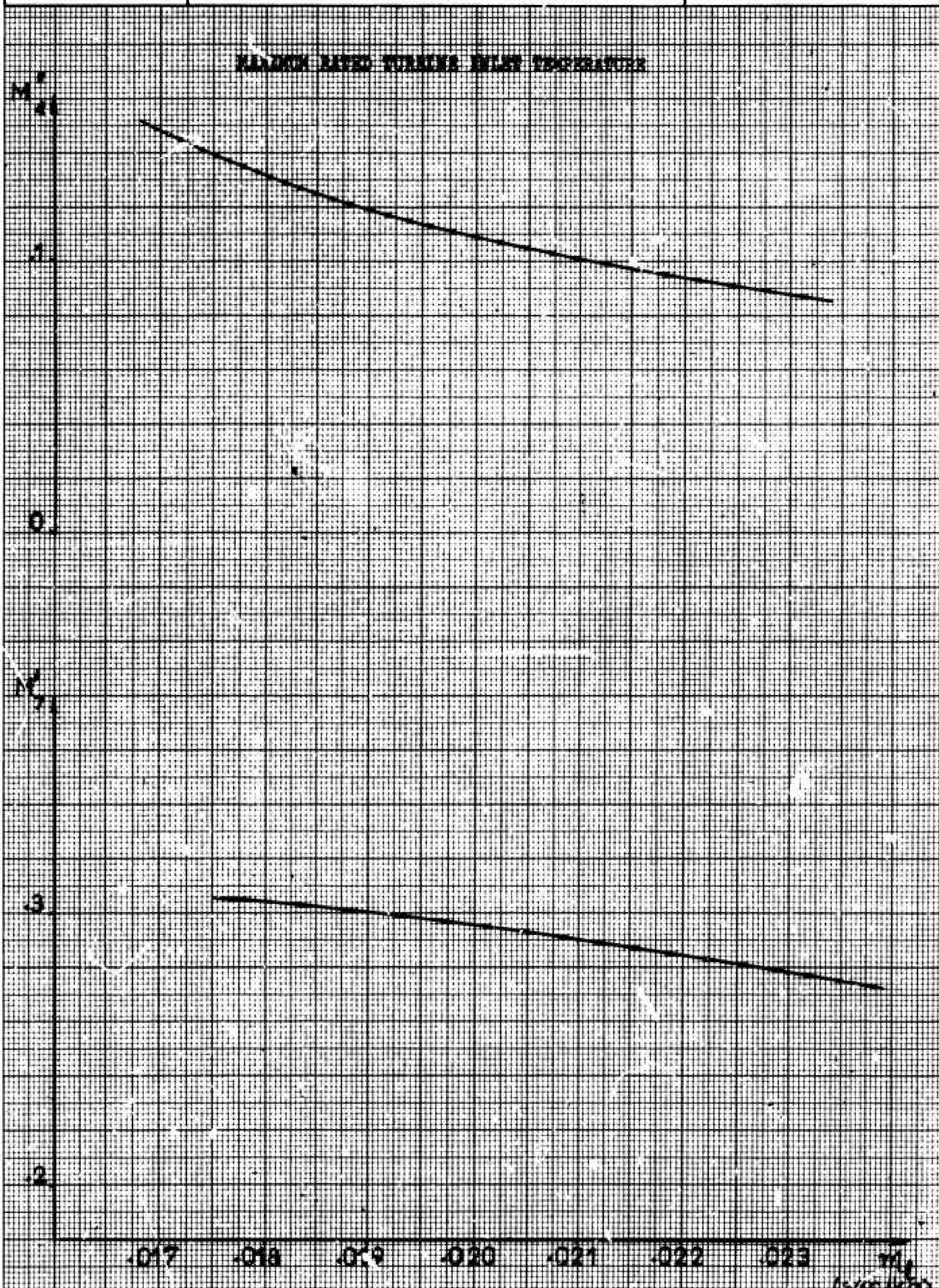
Nord-Aviation	TURBOFAN OPERATION Mo = 1 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 28



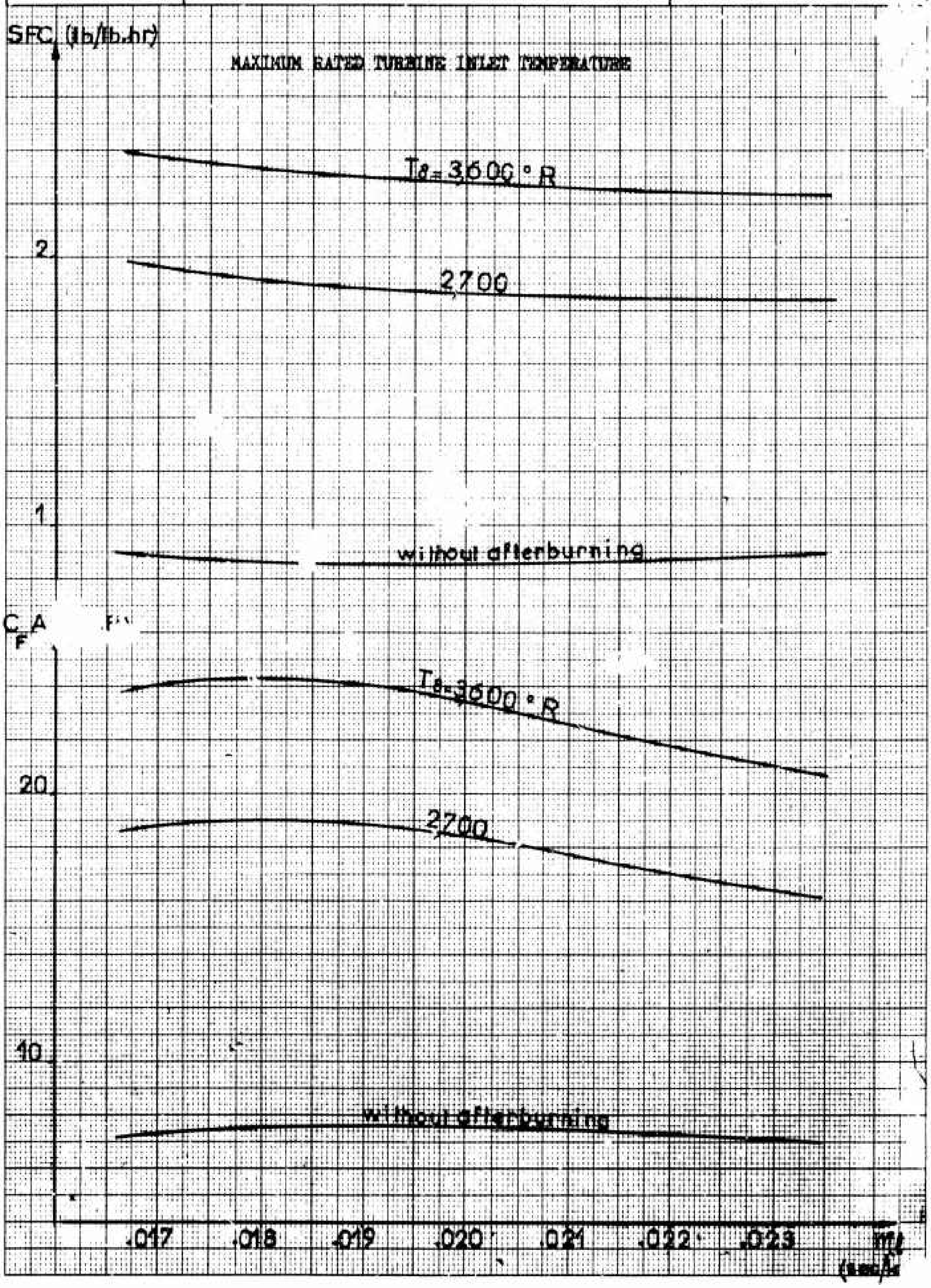
Nord-Aviation	TURBOFAN OPERATION Mo = 1 Z = 36 000 ft	5152/NIOBE IV/34/Z figure 29



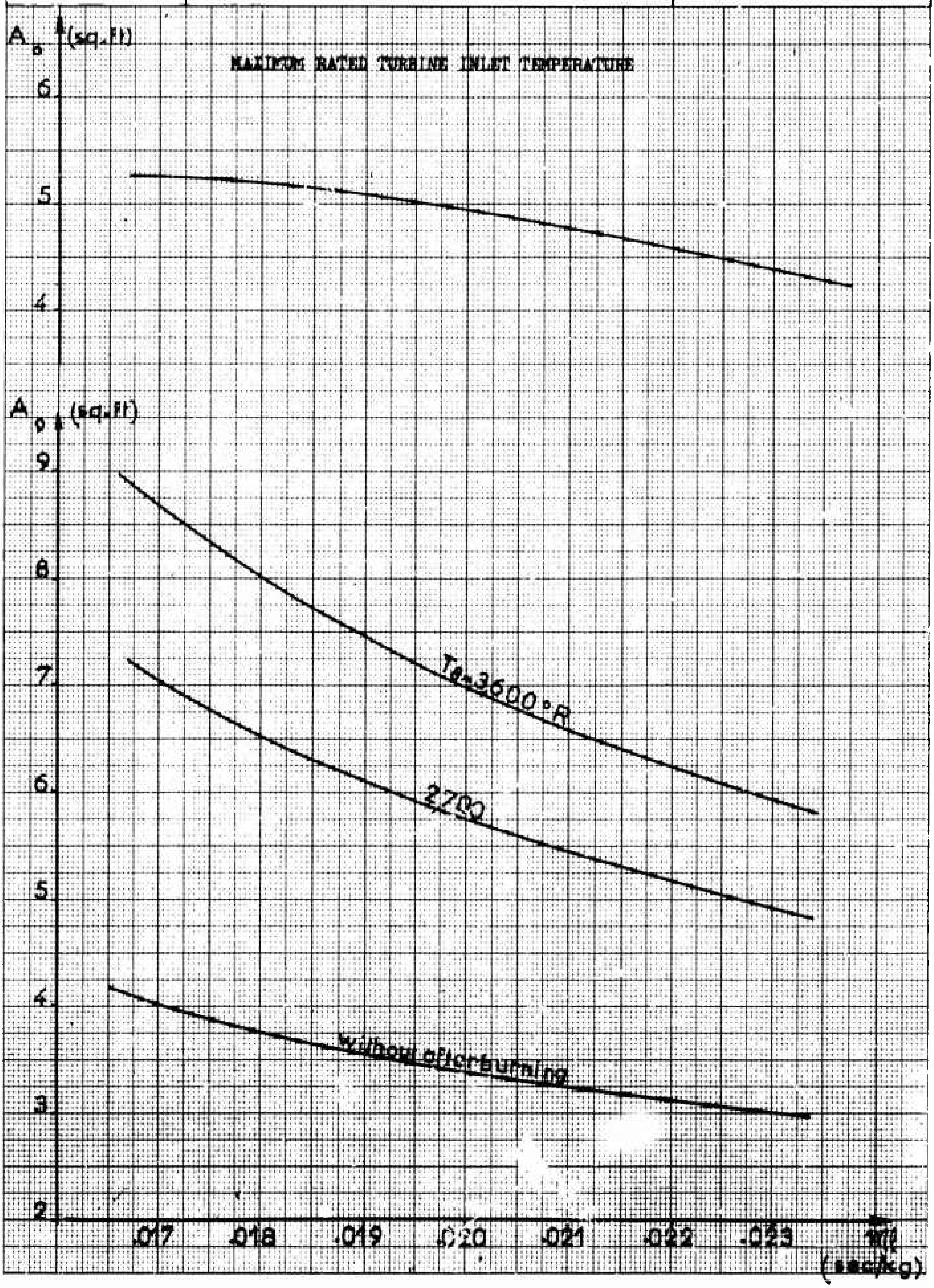
Nord-Aviation	TURBOFAN OPERATION Mo = 1 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 30



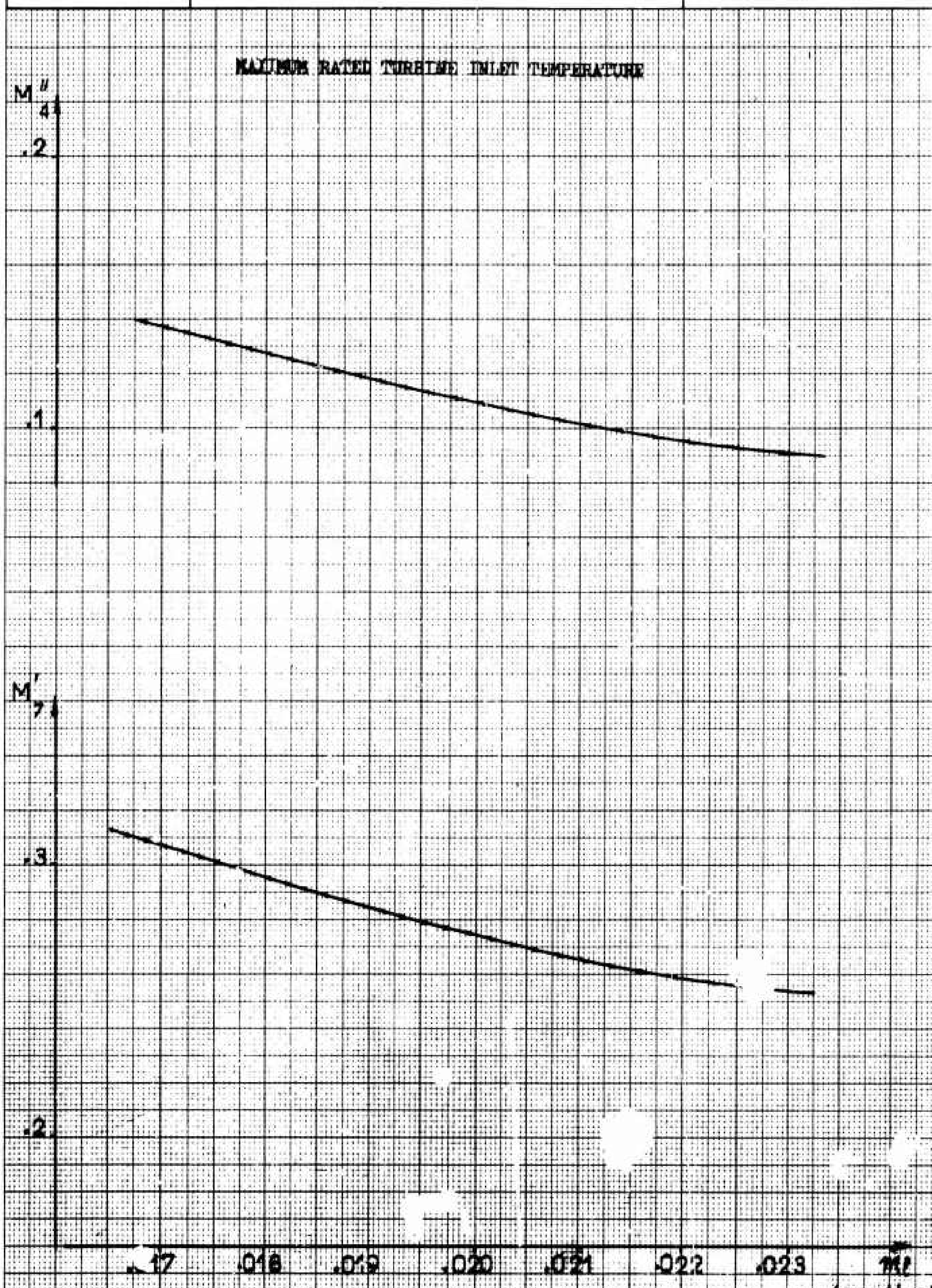
Nord-Aviation	TURBOFAN OPERATION Mo = 1.29 Z = 36 000 ft	5152/NIOBE IV/34 Figure 31



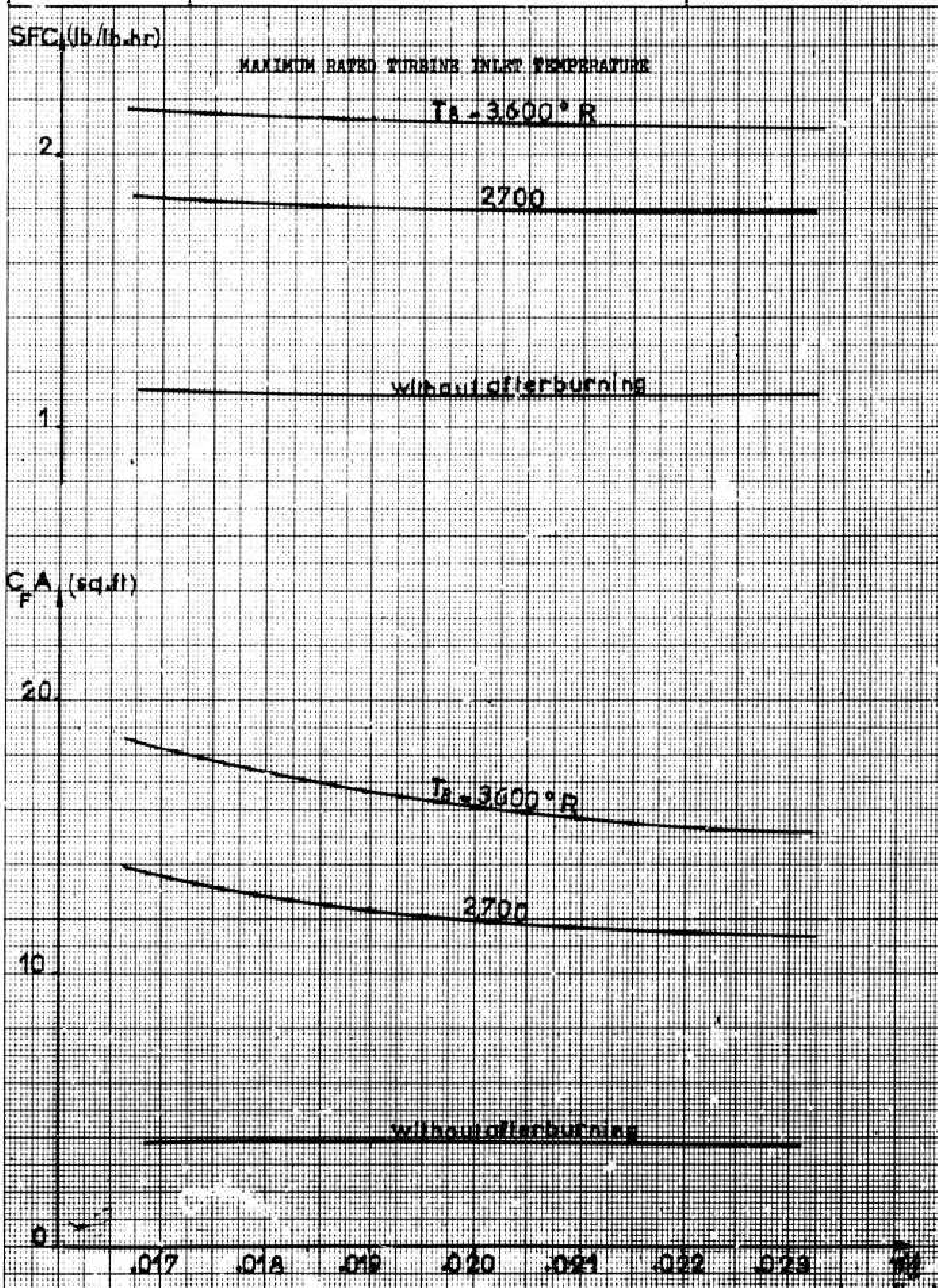
Nord-Aviation	TURBOFAN OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.29 Z = 36 000 ft	Figure 32



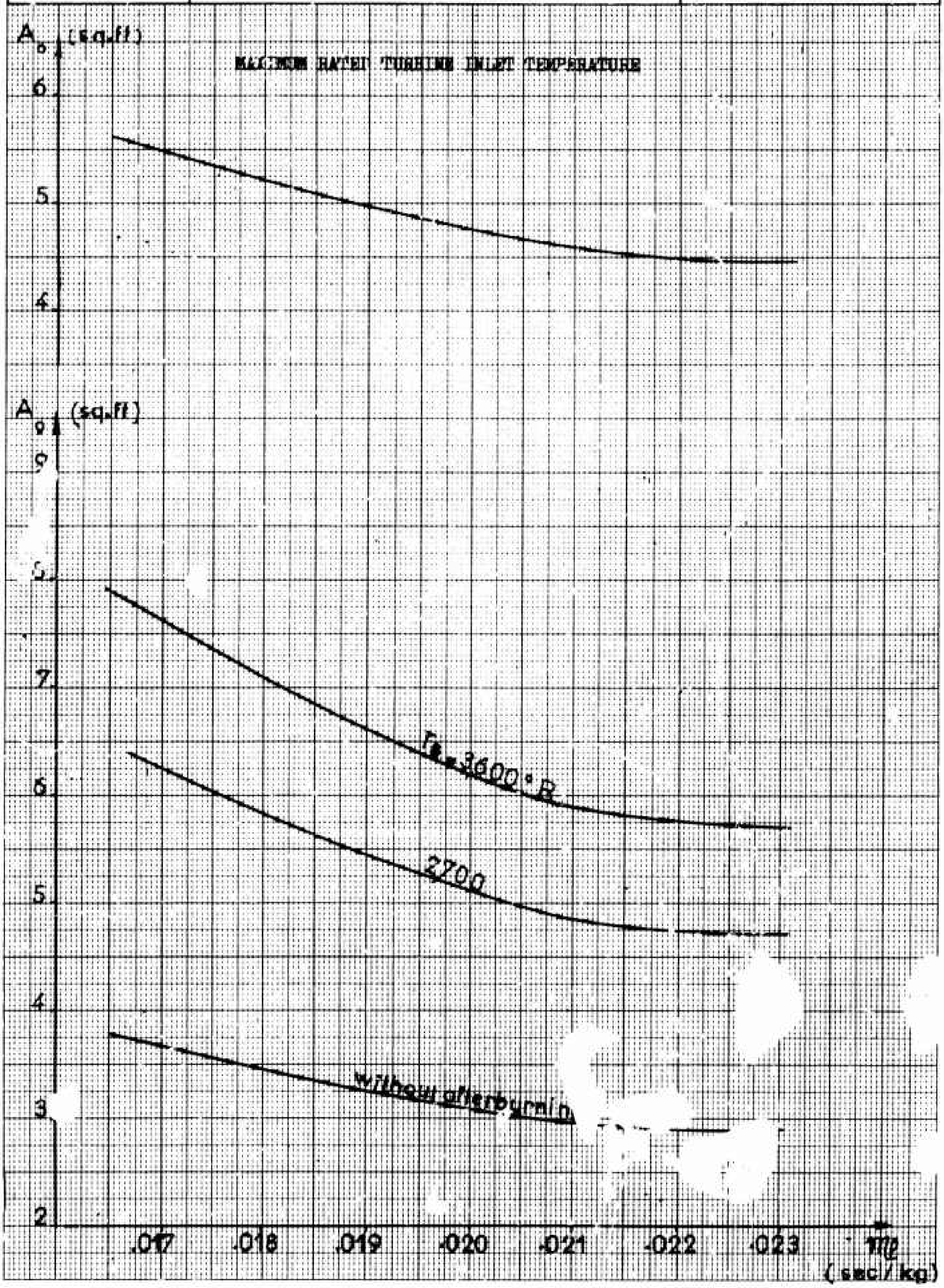
Nord-Aviation	TURBOFAN OPERATION Mo = 1.29 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 33



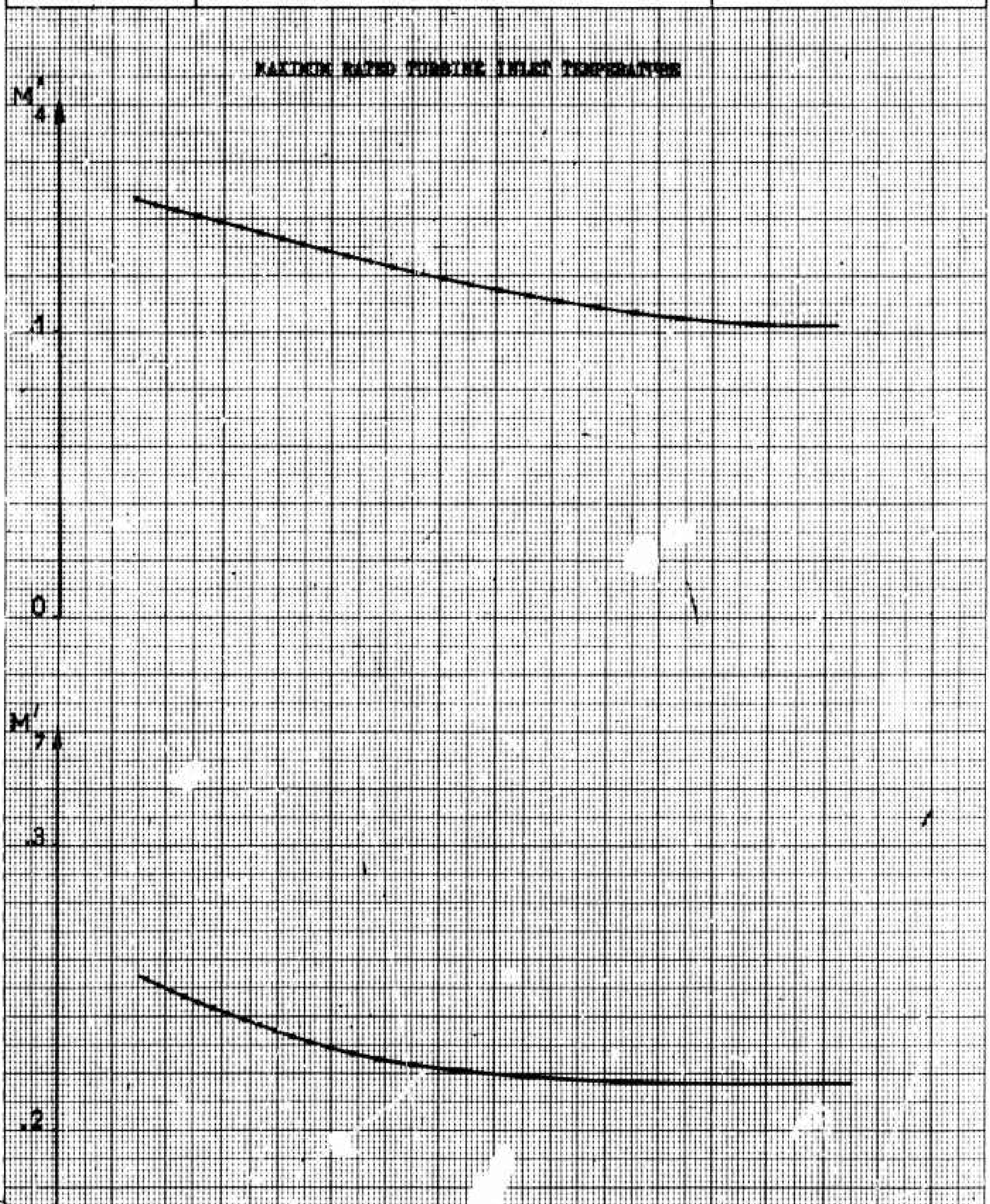
Nord Aviation	TURBOFA O' ERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 34



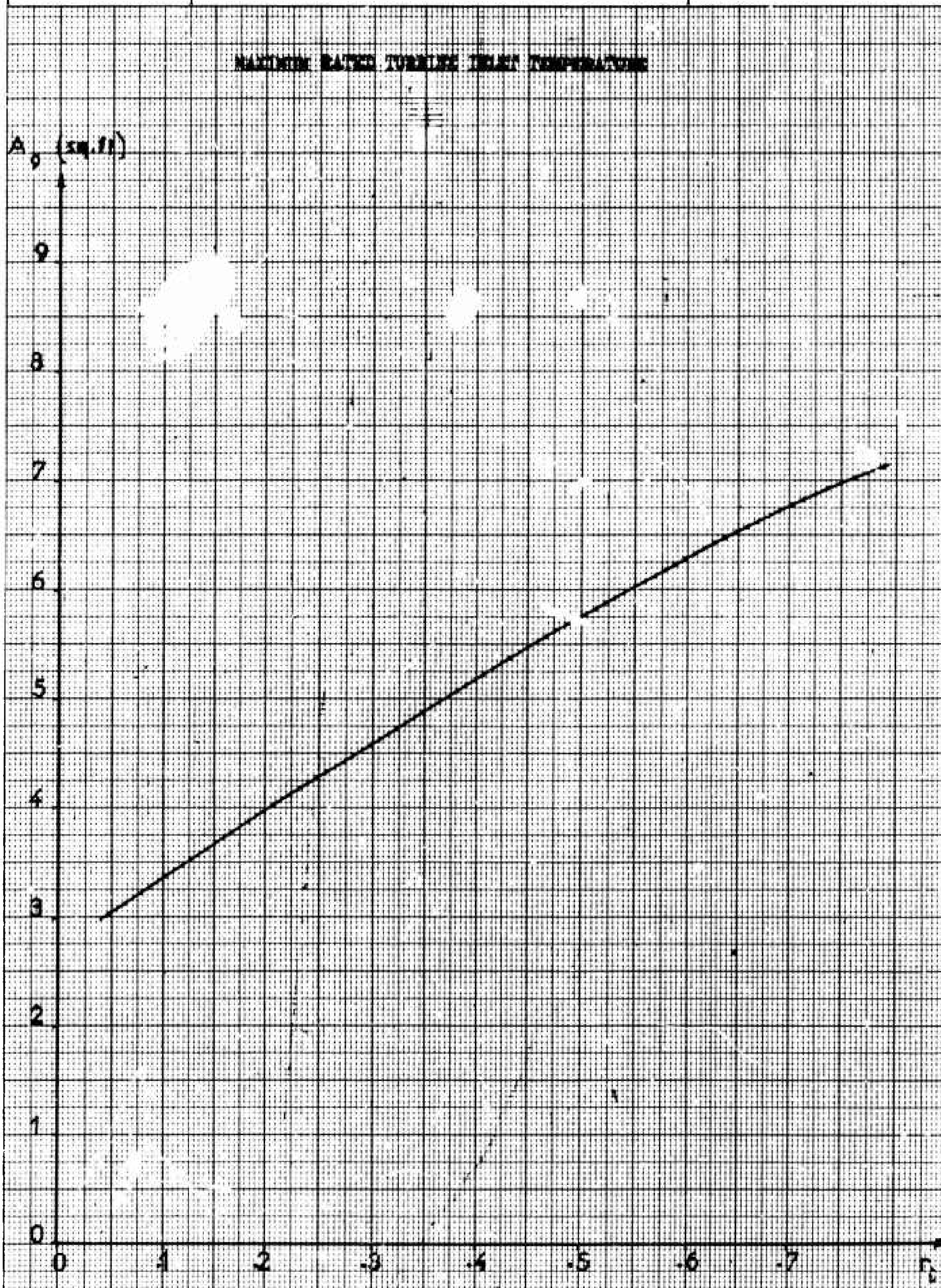
Nord-Aviation	TURBOFAN OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 35



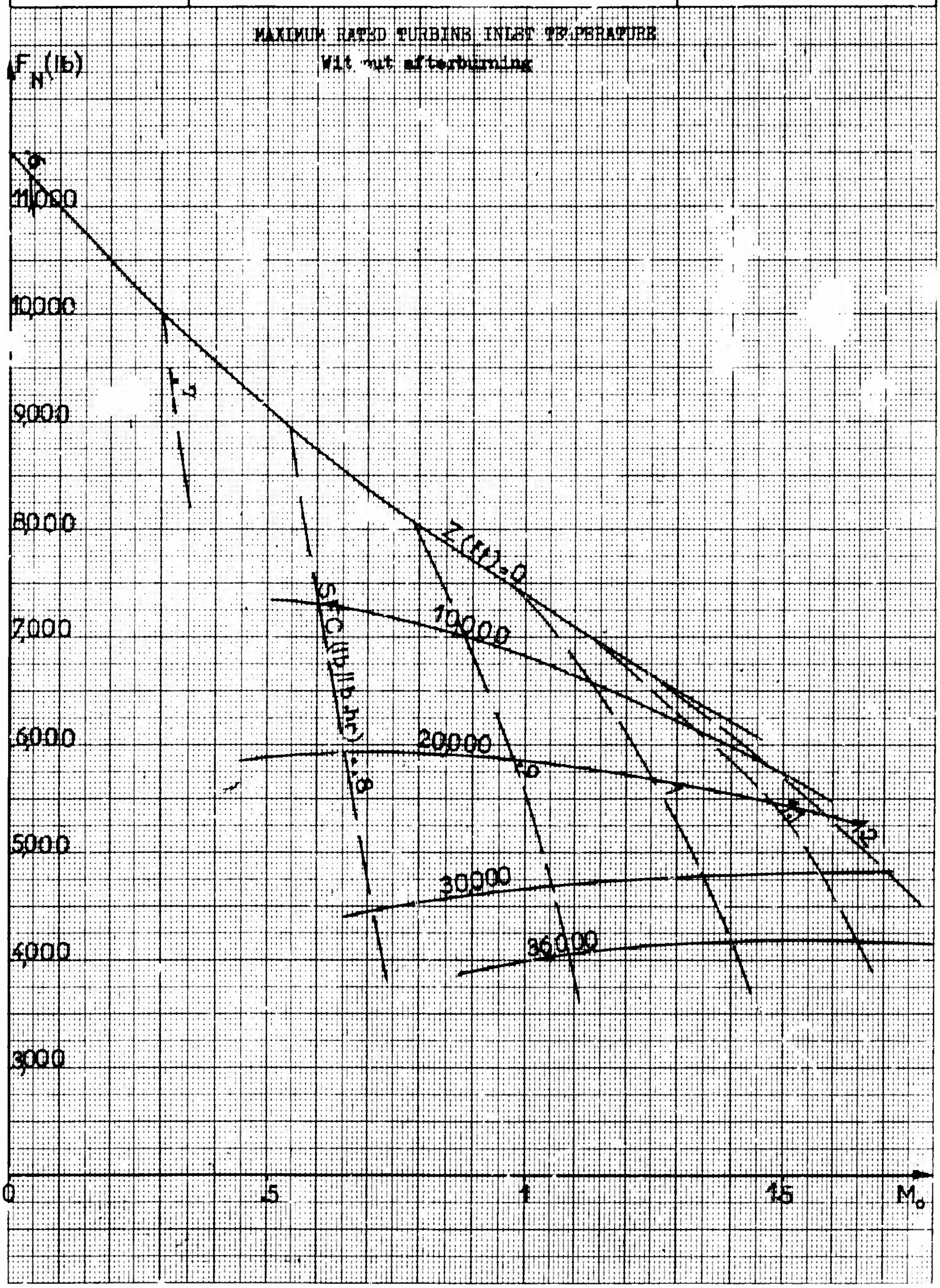
Nord-Aviation	TURBOFAN OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z figure 36



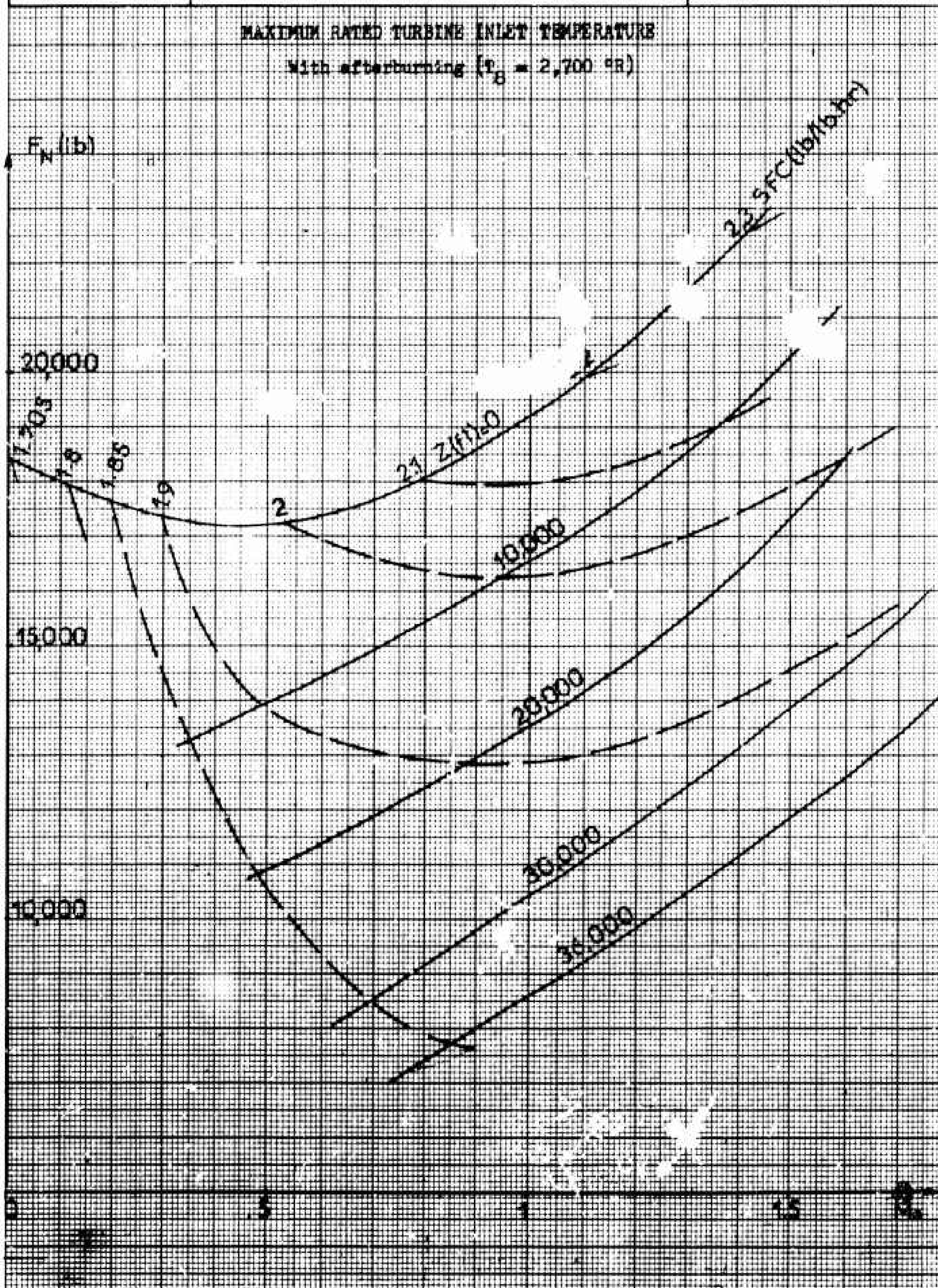
Nord-Aviation	TURBOFAN OPERATION Nozzle throat and fuel control	5152/NIOBE IV/34/Z Figure 37



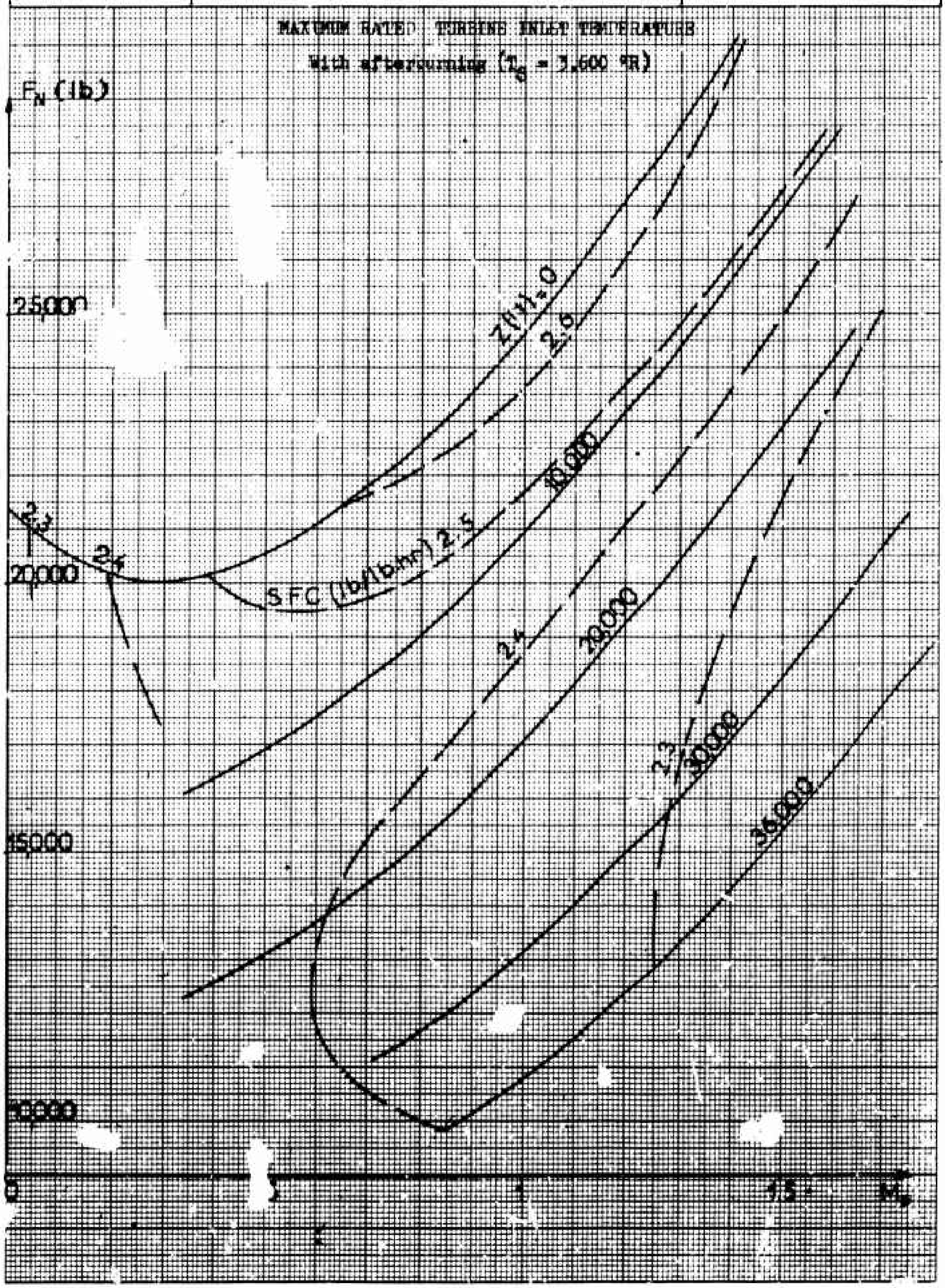
Nord-Aviation	TURBOFAN OPERATION Performance characteristics	5152/NIOBE IV/34/Z Figure 38



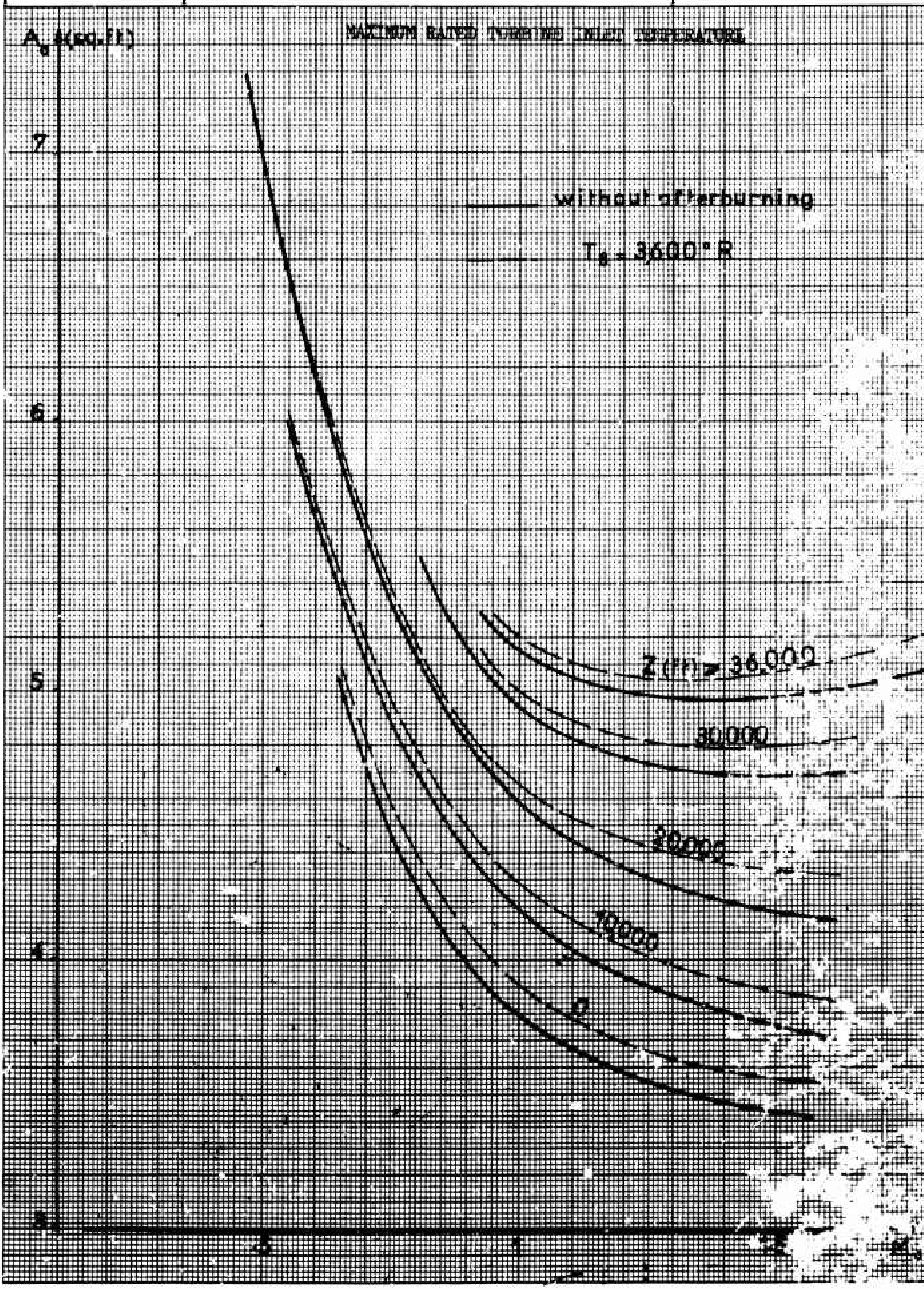
Nord-Aviation	TURBOFAN OPERATION Performance characteristics	5152/NIOBE IV/34/Z Figure 39



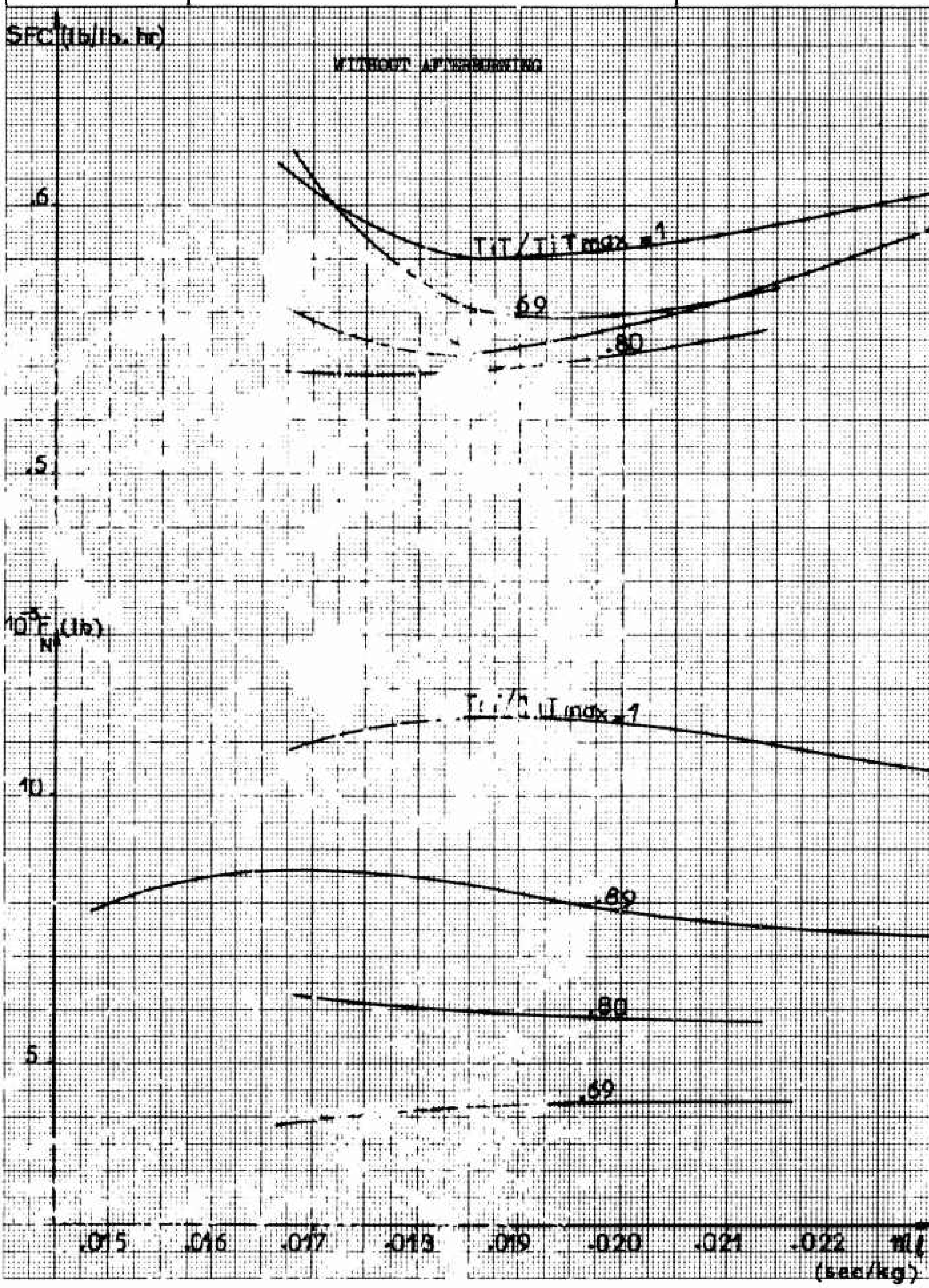
Nord-Aviation	TURBOFAN OPERATION	5152/NIOBE IV/34/2
	Performance characteristics	**Figure** 40



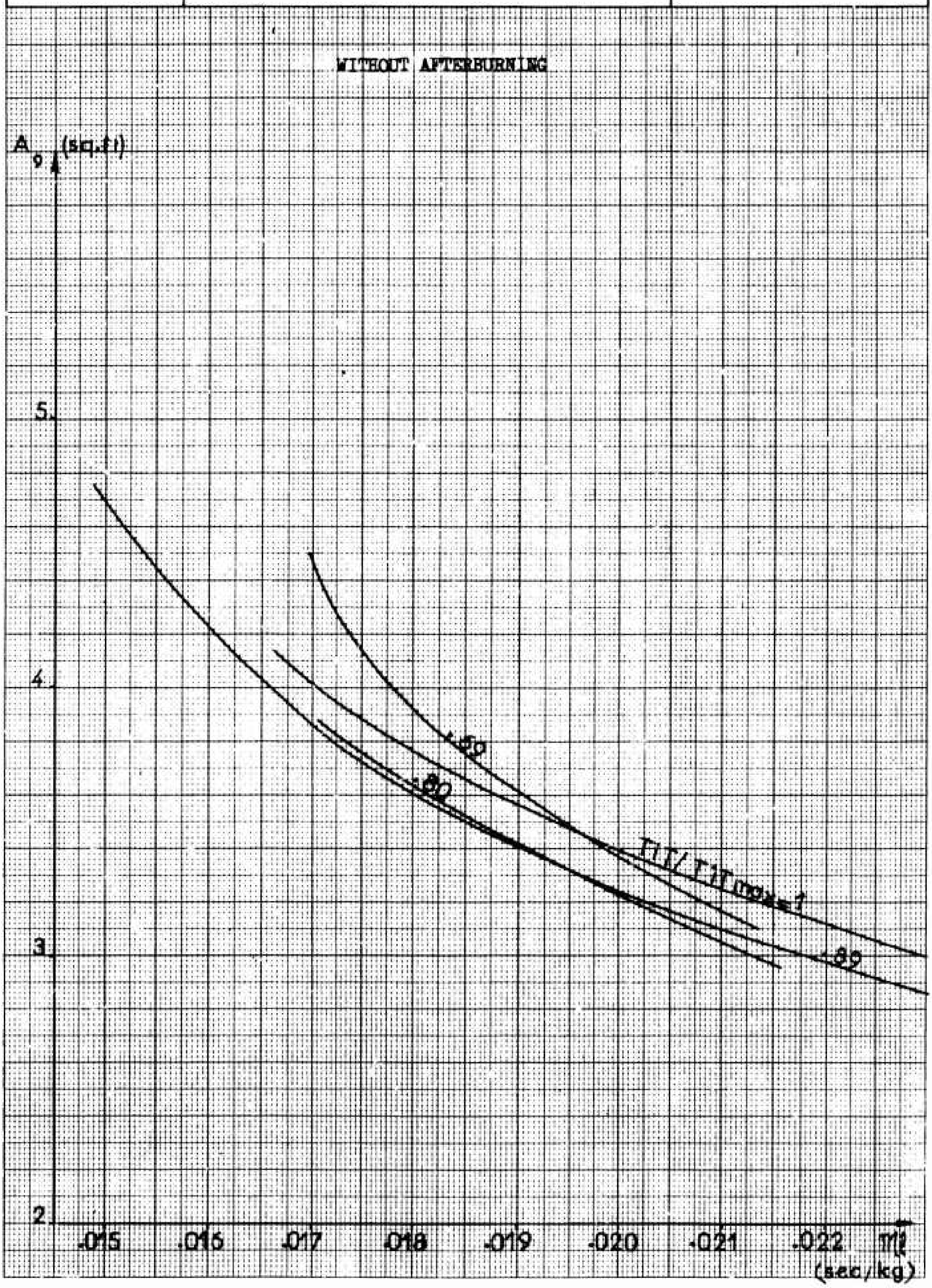
Nord-Aviation	TURBOFAN OPERATION AIR CAPTURE AREA	5152/NIOBE IV/34/Z Figure 41



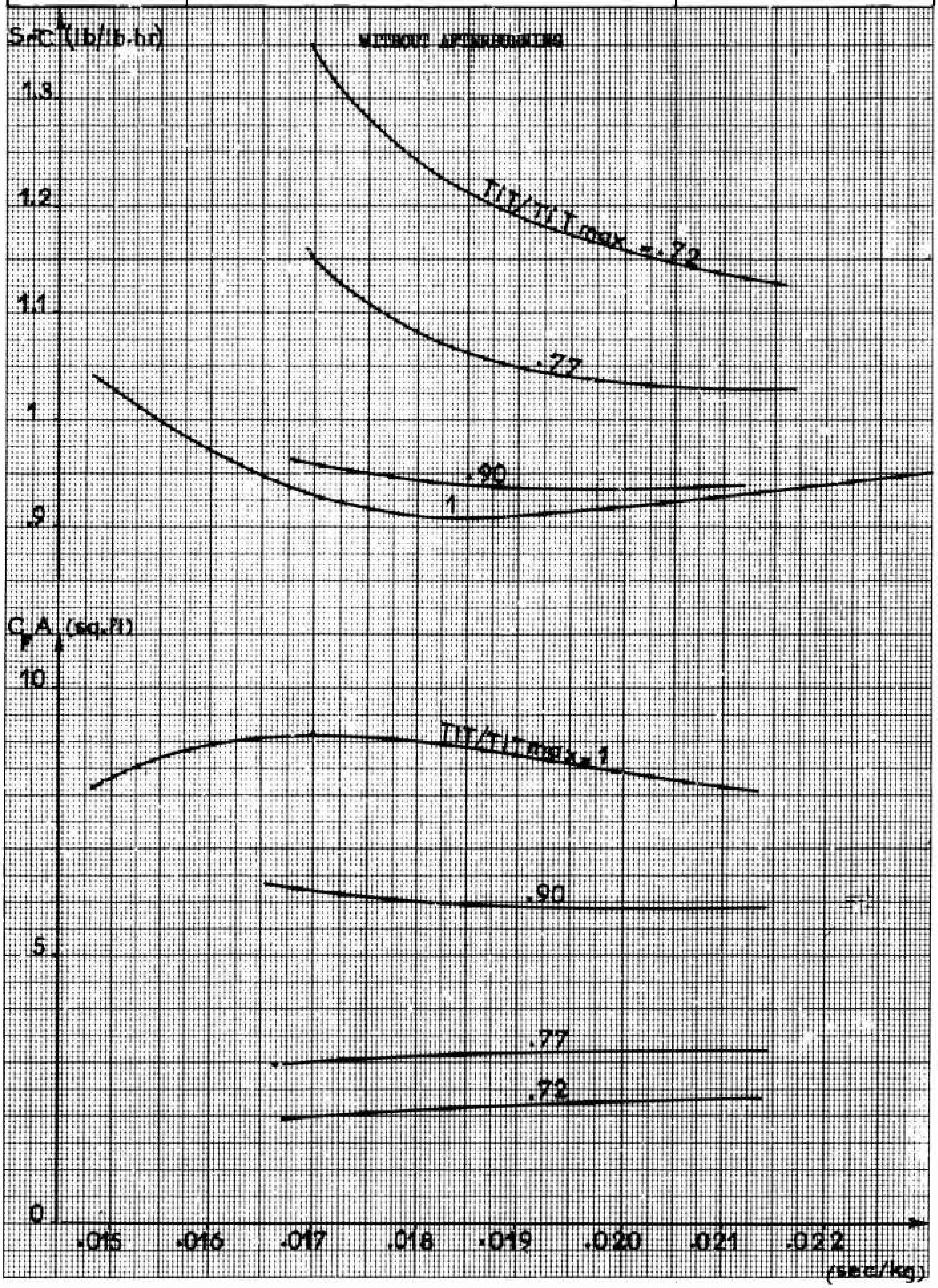
Nord-Aviation	TURBOFAN OPERATION Mo = 0 Z = 0	5152/NIOBE IV/34/Z Figure 42



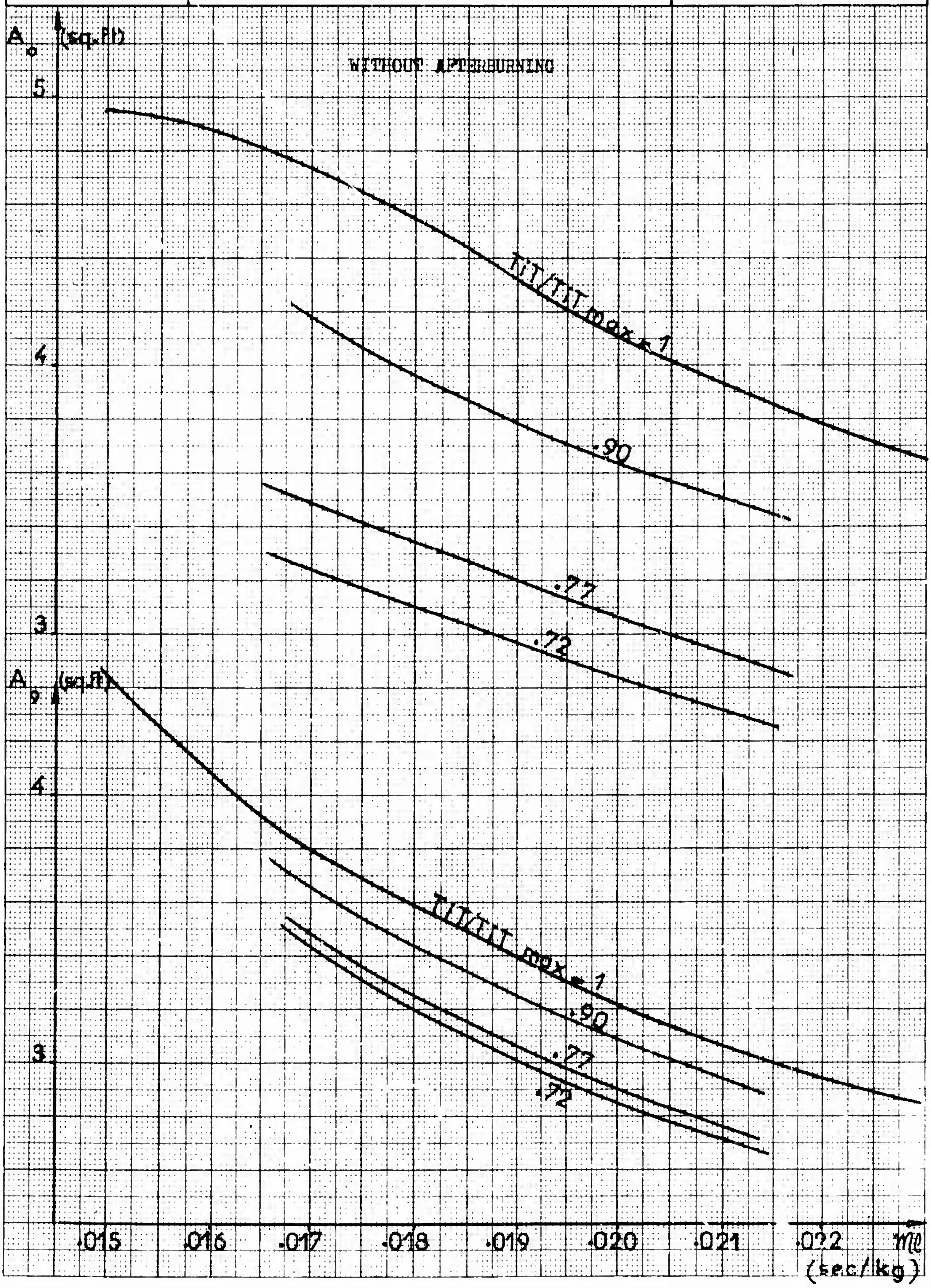
Nord-Aviation	TURBOFAN OPERATION Mo = 0 Z = 0	5152/NIOBE IV/34/Z Figure 43



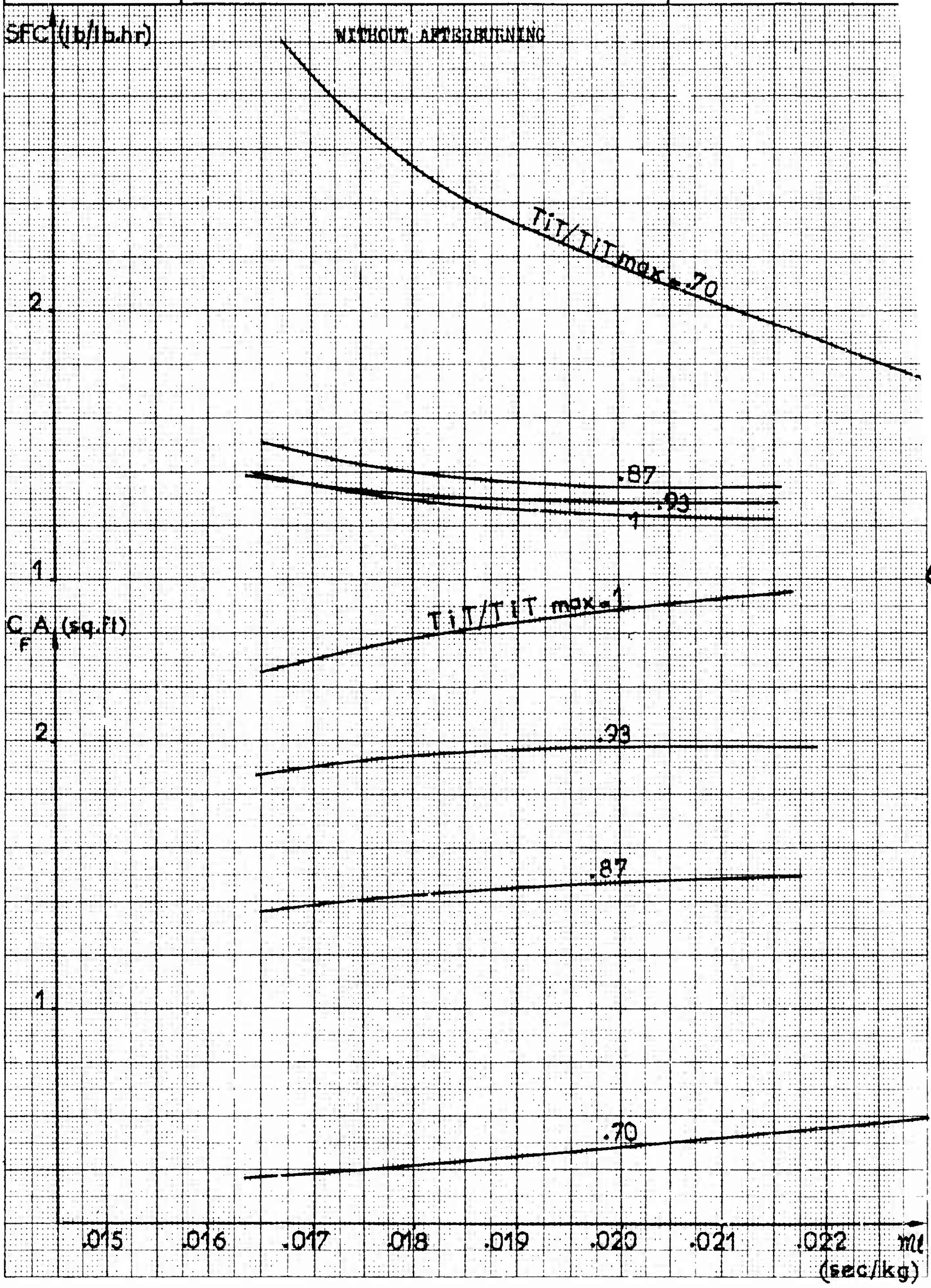
Nord-Aviation	TURBOFAN OPERATION Mo = 0.79 Z = 0	5152/NIOBE IV/34/Z Figure 44



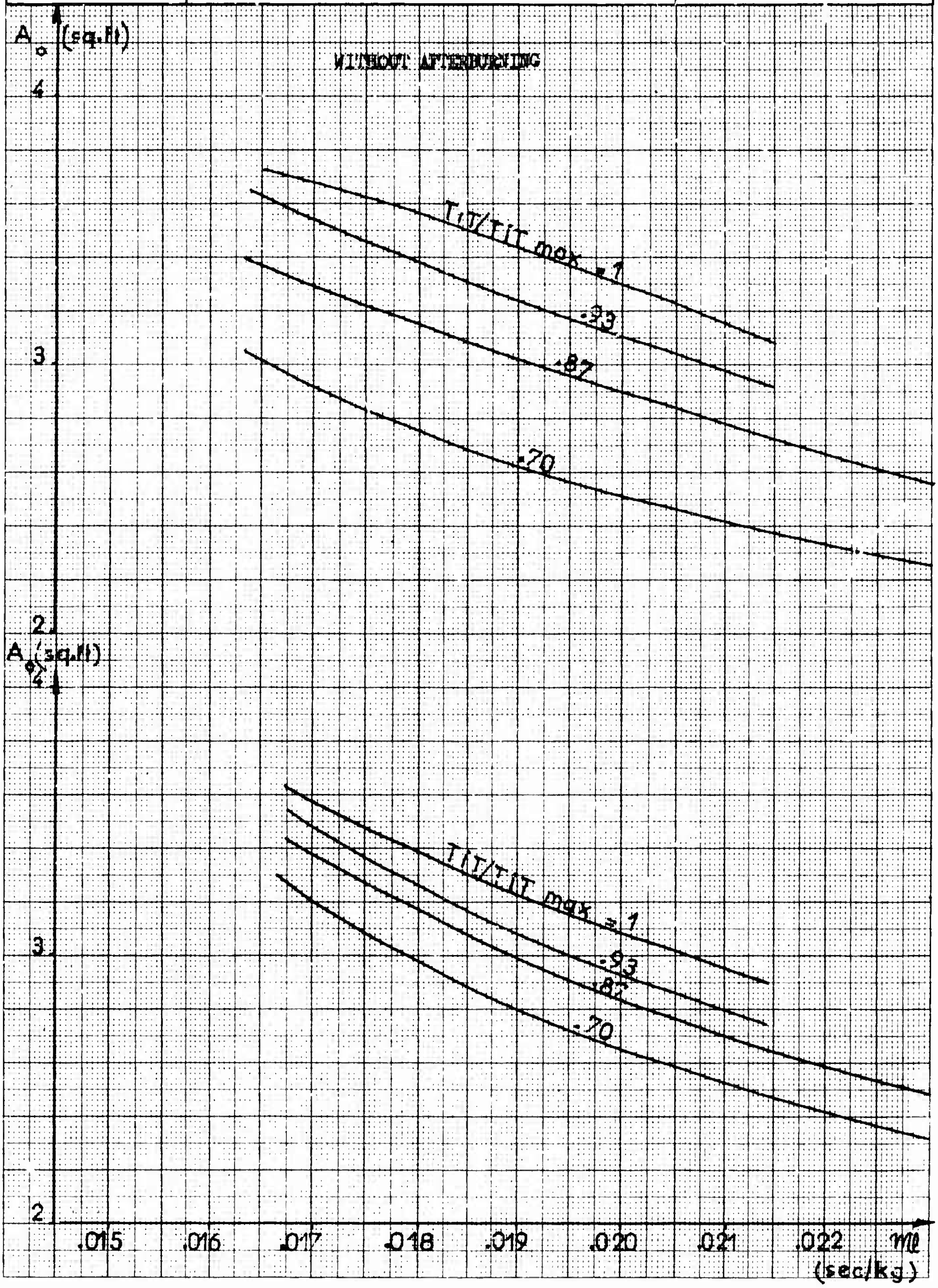
Nord-Aviation	TURBOFAN OPERATION Mo = 0.79 Z = 0	5152/NIOBE IV/34/Z Figure 45



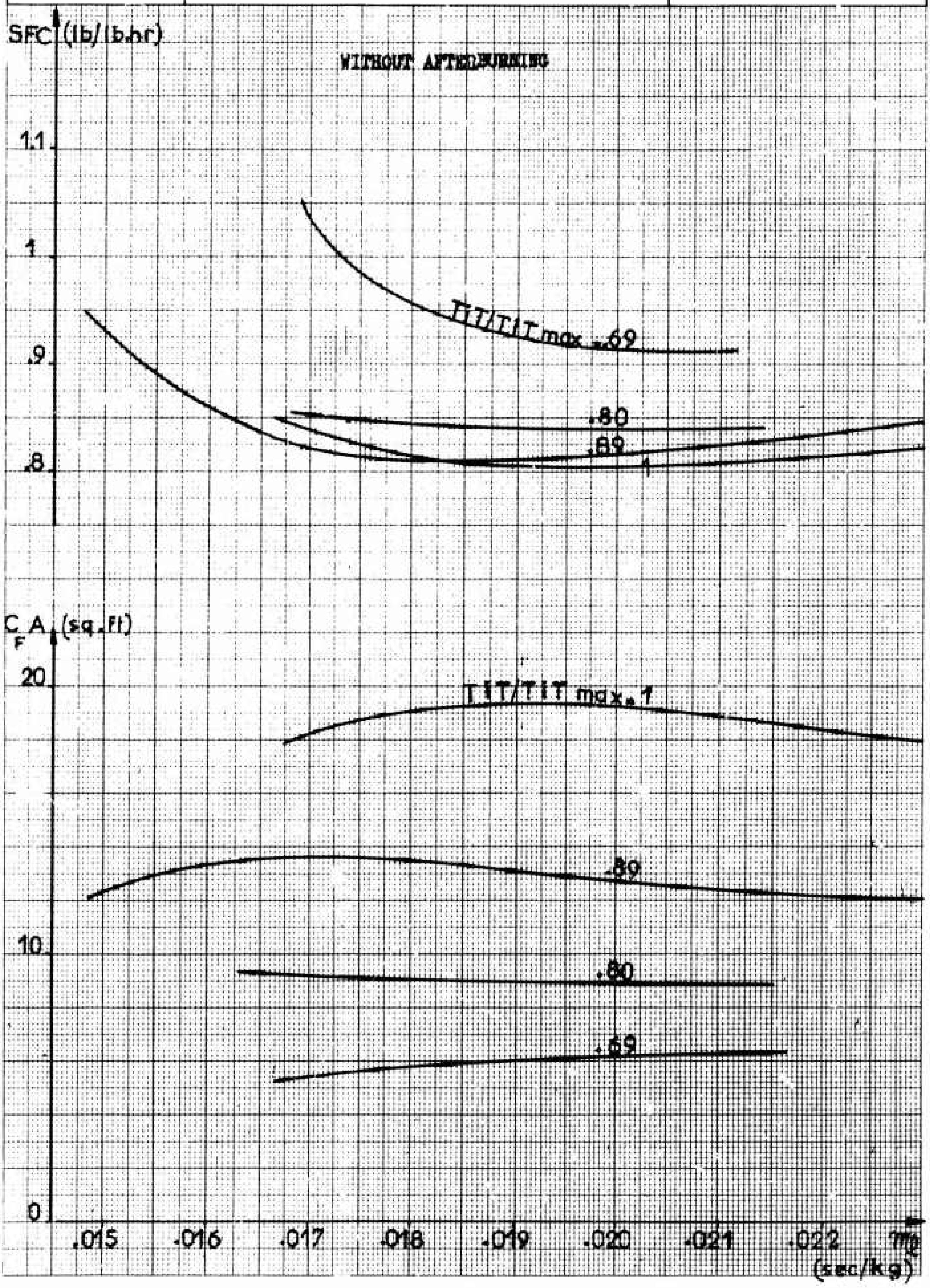
Nord-Aviation	TURBOFAN OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.33 Z = 0	Figure 46



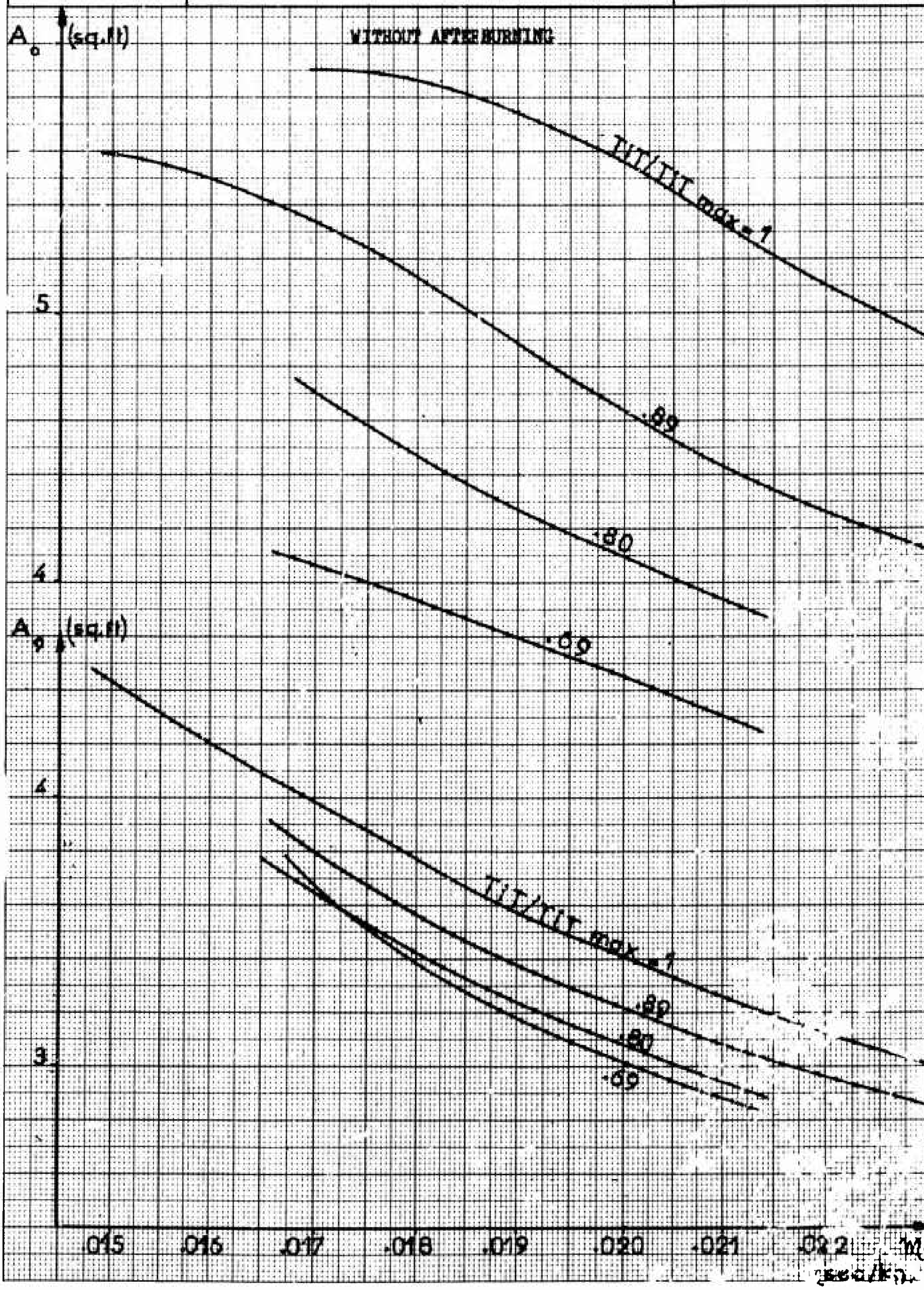
Nord-Aviation	TURBOFAN OPERATION Mo = 1.33 Z = 0	5152/NIOBE IV/34/Z Figure 47



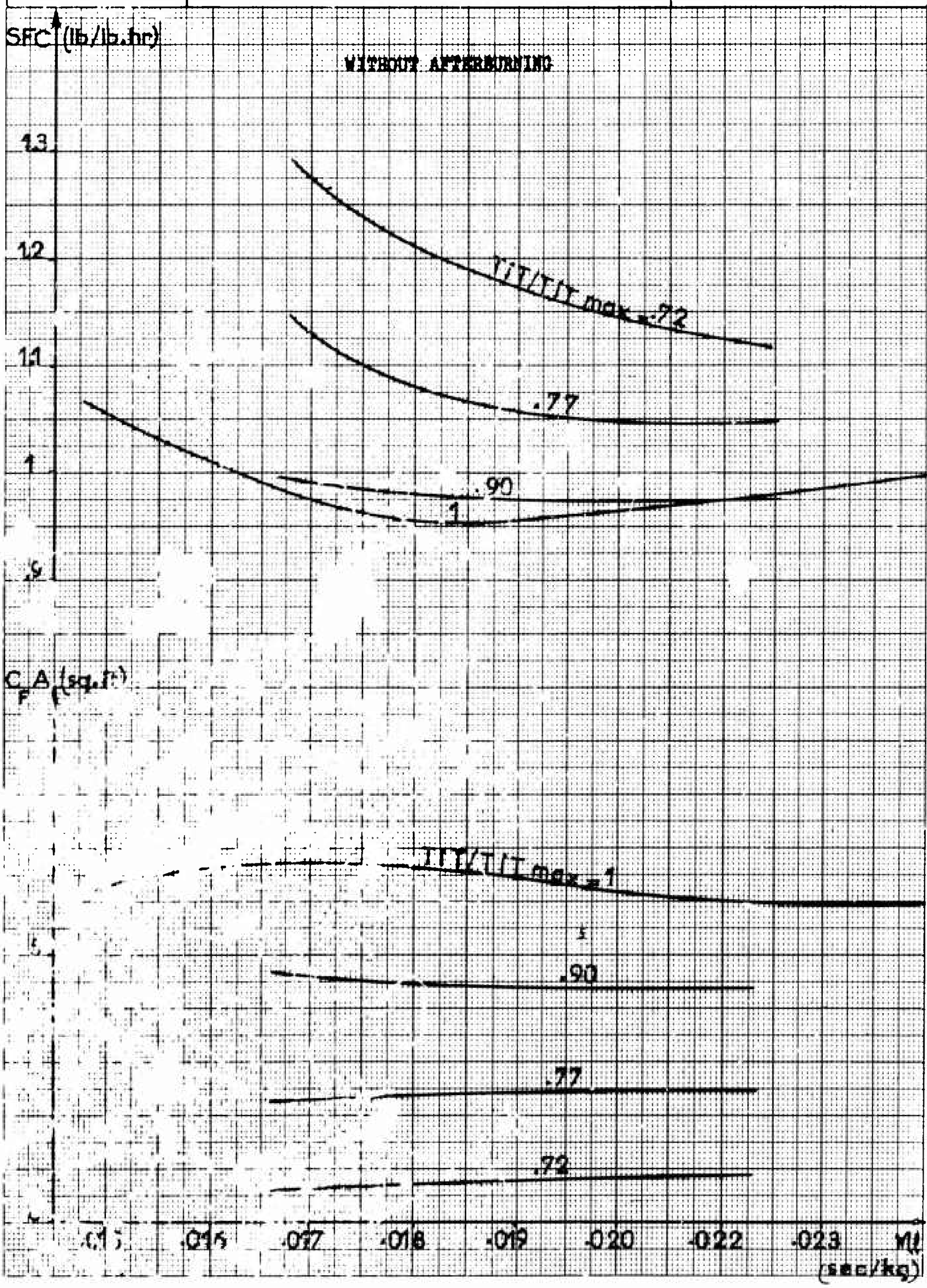
Nord-Aviation	TURBOFAN OPERATION Mo = 0,61 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 48



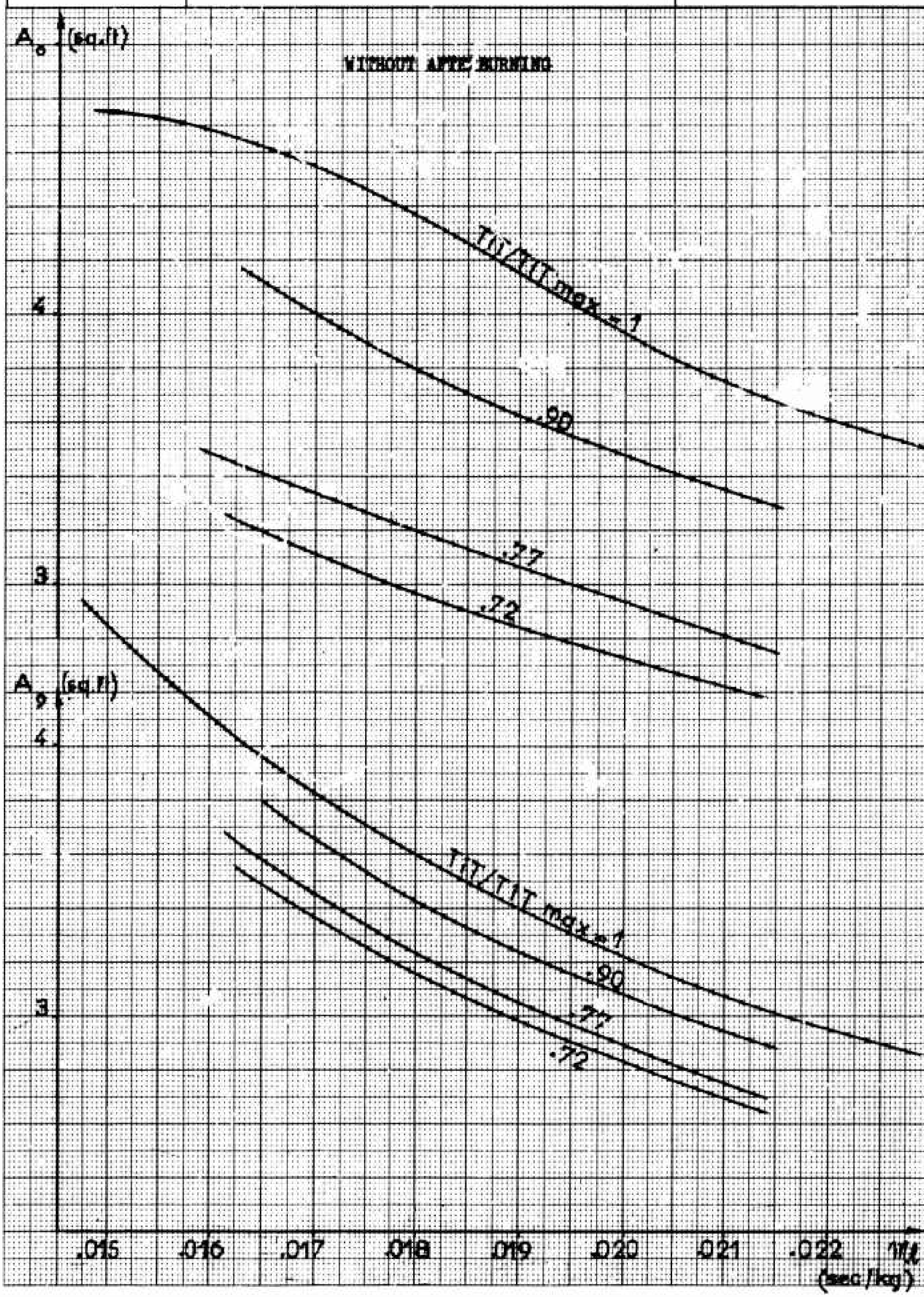
Nord-Aviation	TURBOFAN OPERATION Mo = 0.61 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 49



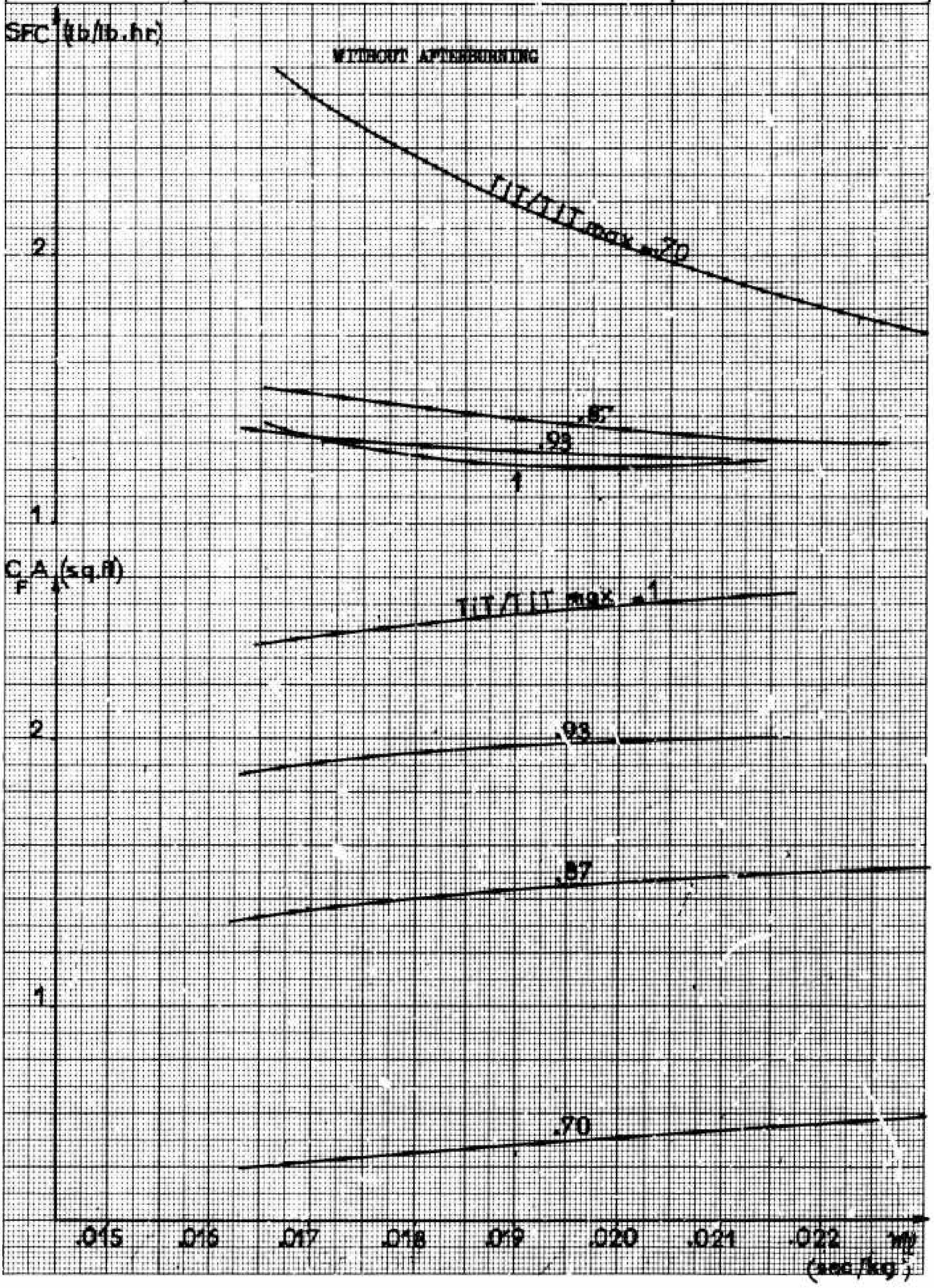
Nord-Aviation	TURBOFAN OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.02 Z = 10 000 ft	Figure 50



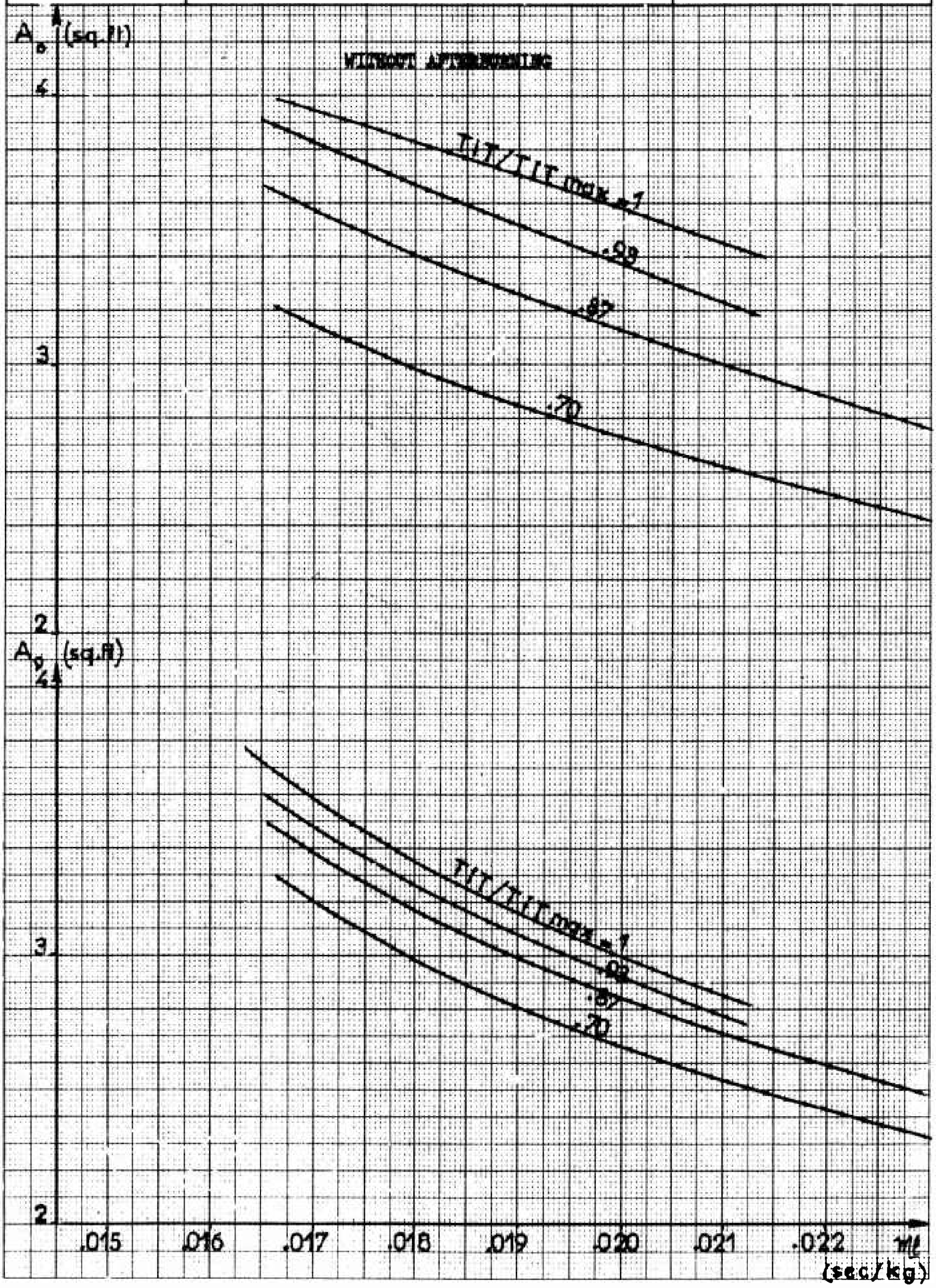
Nord-Aviation	TURBOFAN OPERATION Mo = 1.02 Z = 10 000 ft	5152/NIOBE IV/34/Z Figure 51



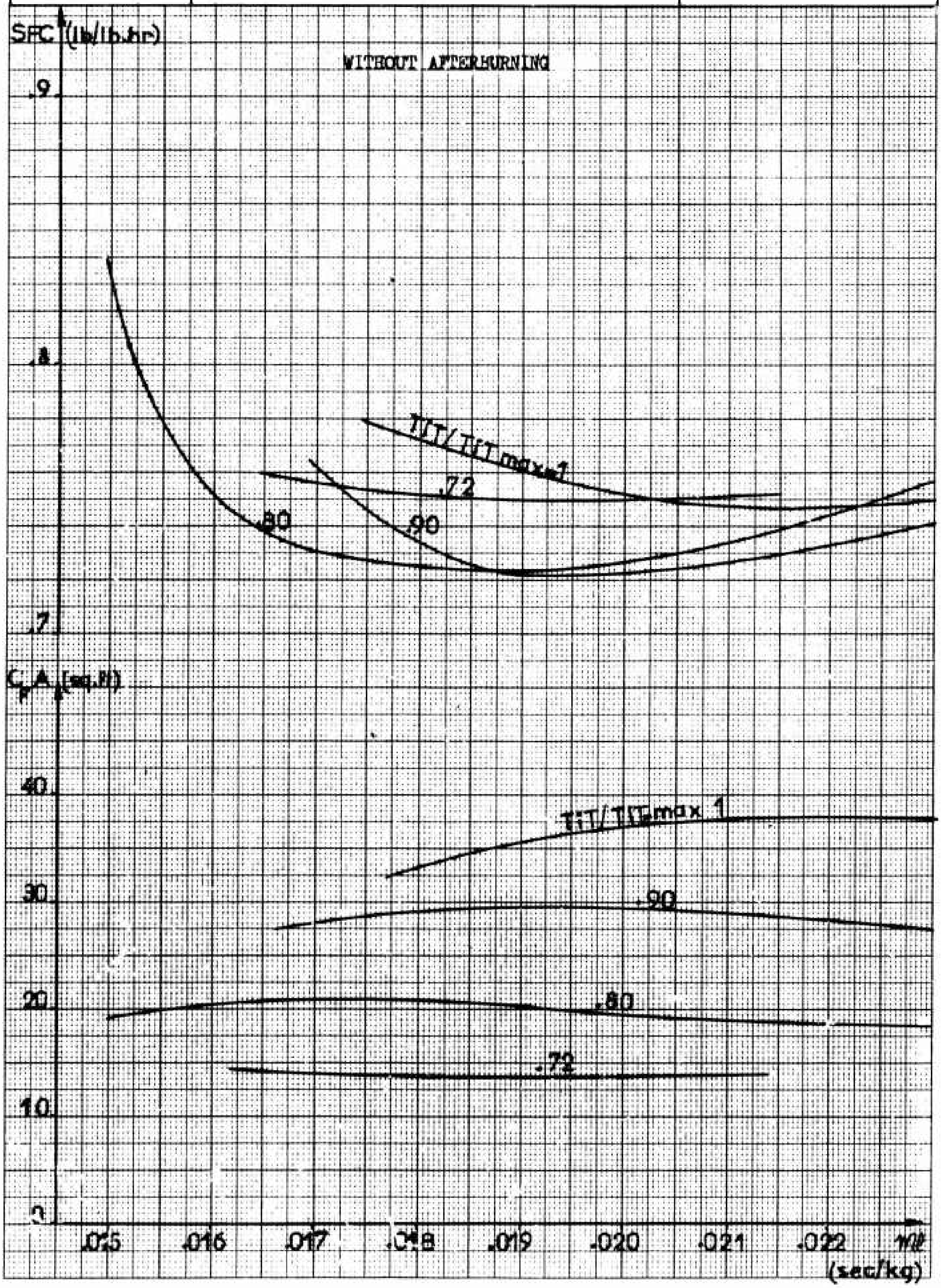
Nord-Aviation	TURBOFAN OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.51 Z = 10 000 ft	Figure 52



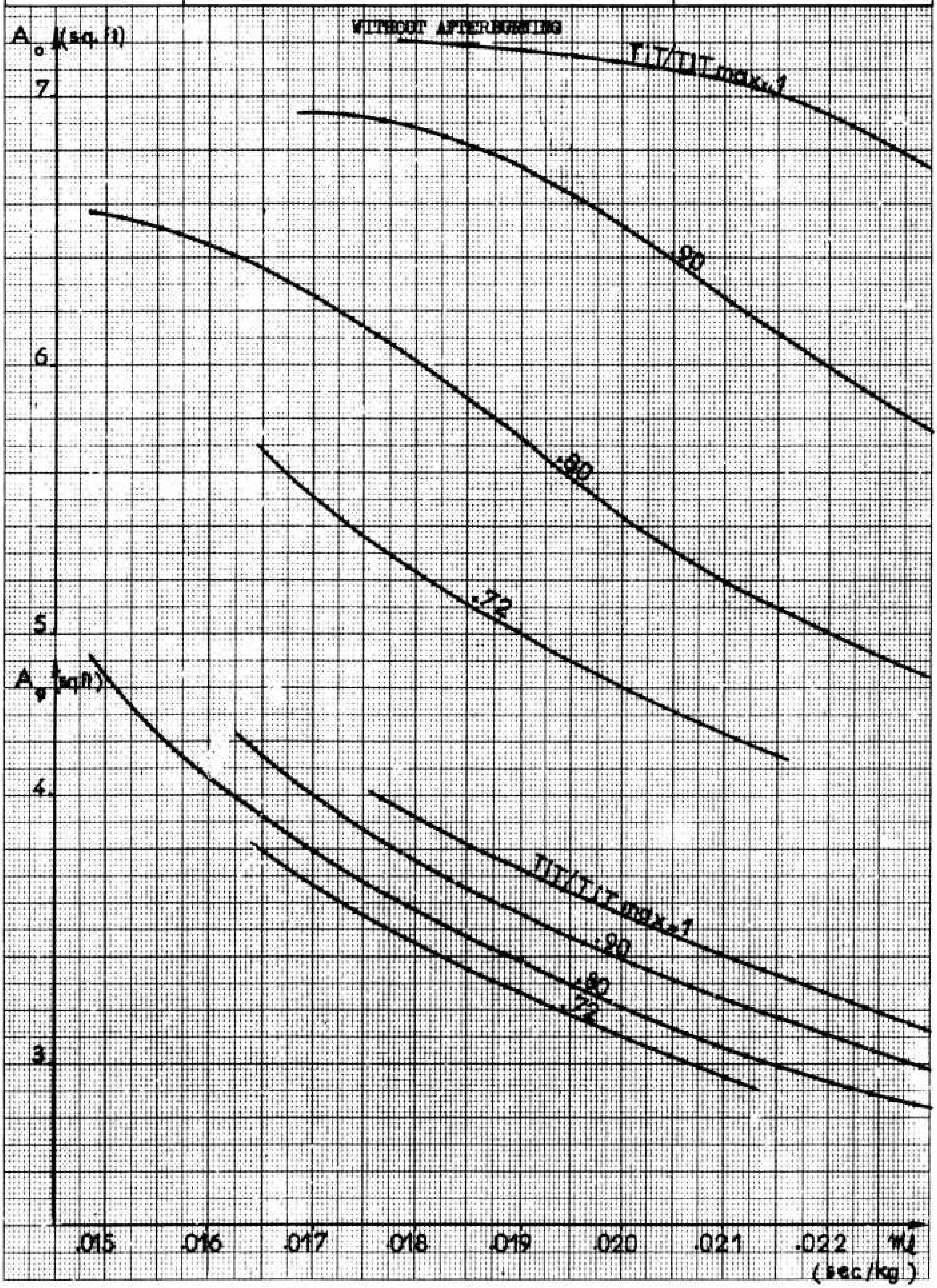
Nord-Aviation	TURBOFAN OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.51 Z = 10 000 ft	FIGURE 53



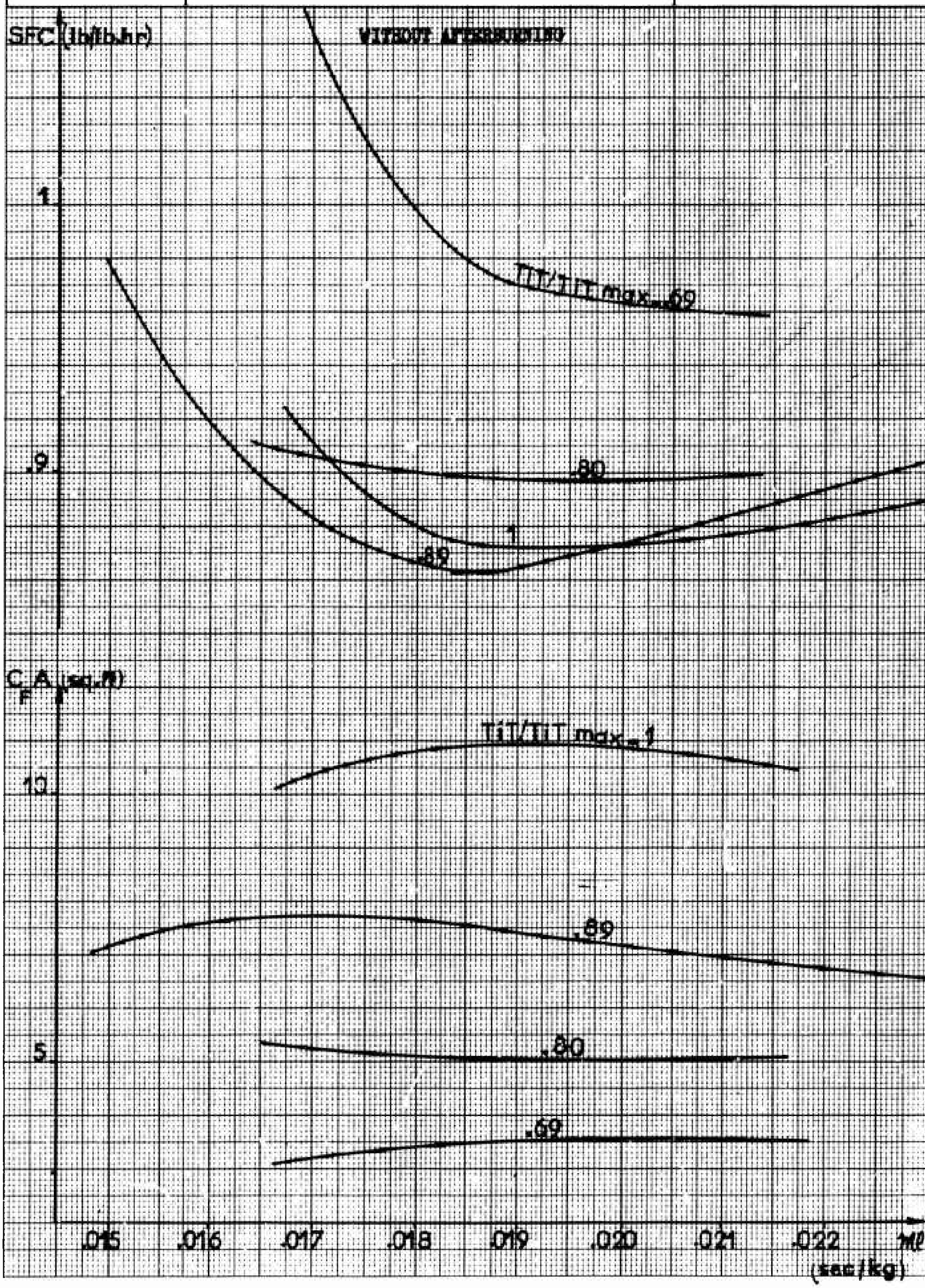
Nord-Aviation	TURBOFAN OPERATION Mo = 0.48 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 54



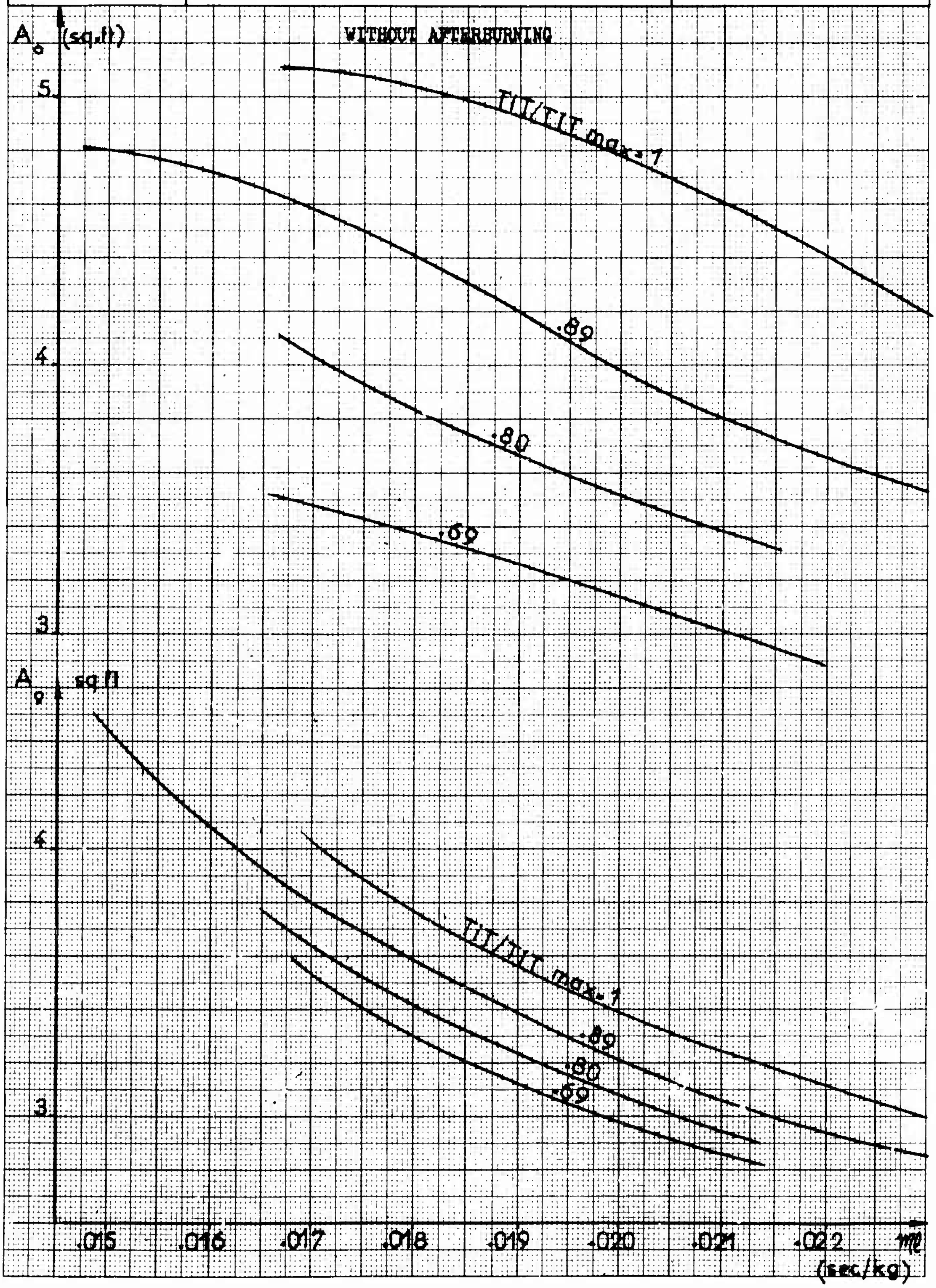
Nord-Aviation	TURBOFAN OPERATION Mo = 0.48 Z = 20 000 ft	5152/NIOBE IV/34/2 Figure 55



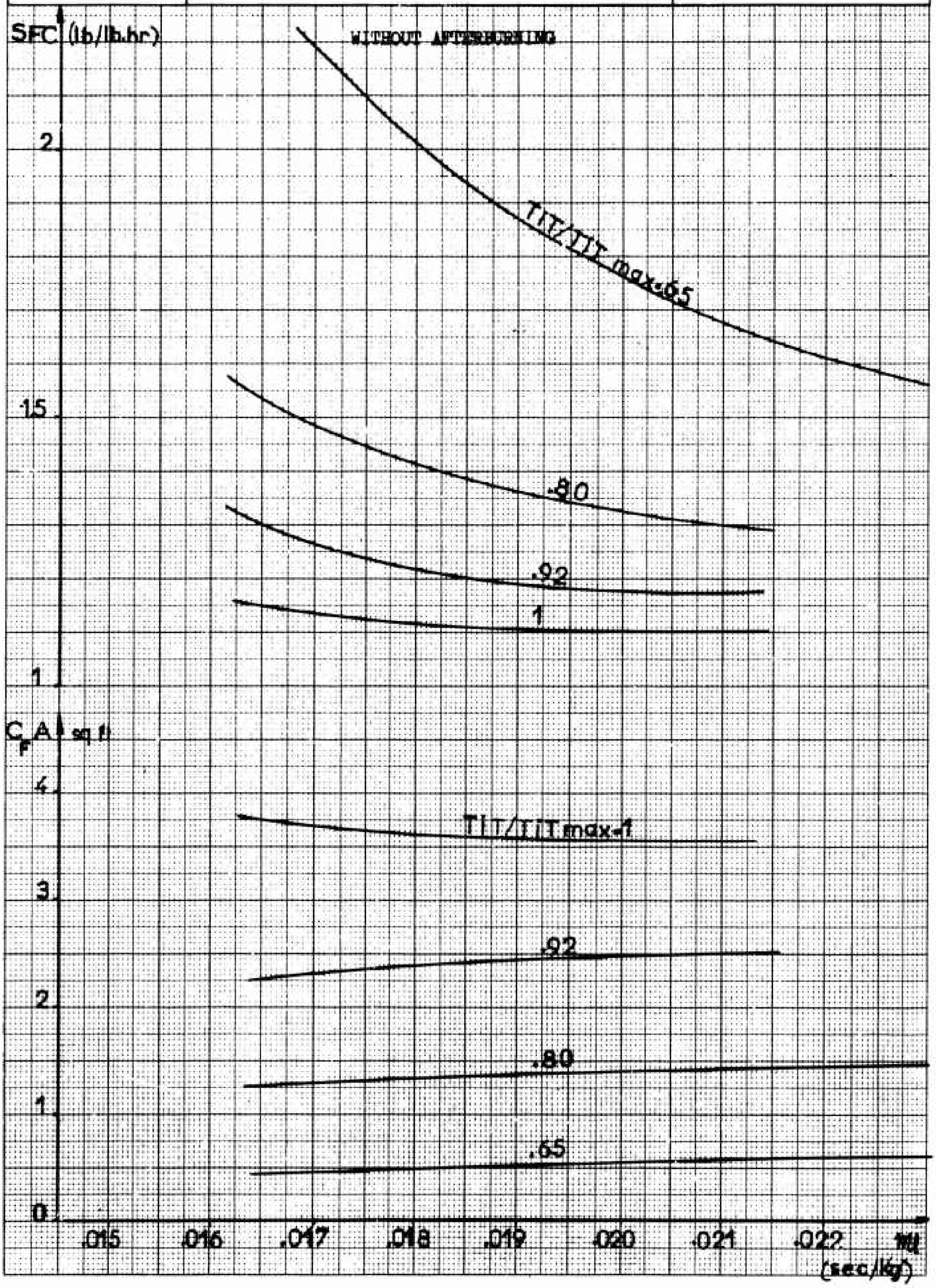
Nord-Aviation	TURBOFAN OPERATION Mo = 0.89 Z = 20 000 ft	5152/NIOBEIV/34/Z Figure 56



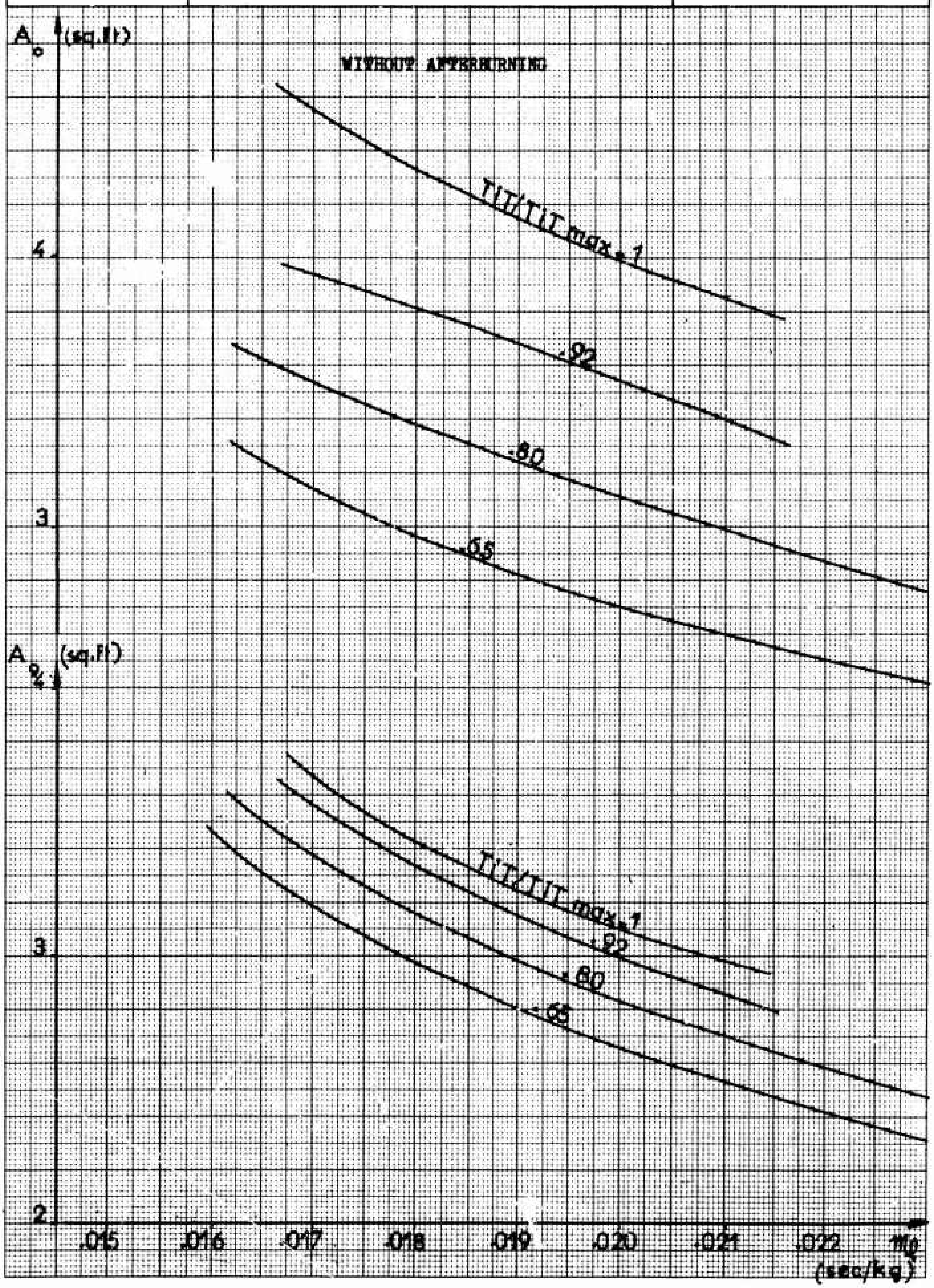
Nord-Aviation	TURBOFAN OPERATION Mo = 0.89 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 57



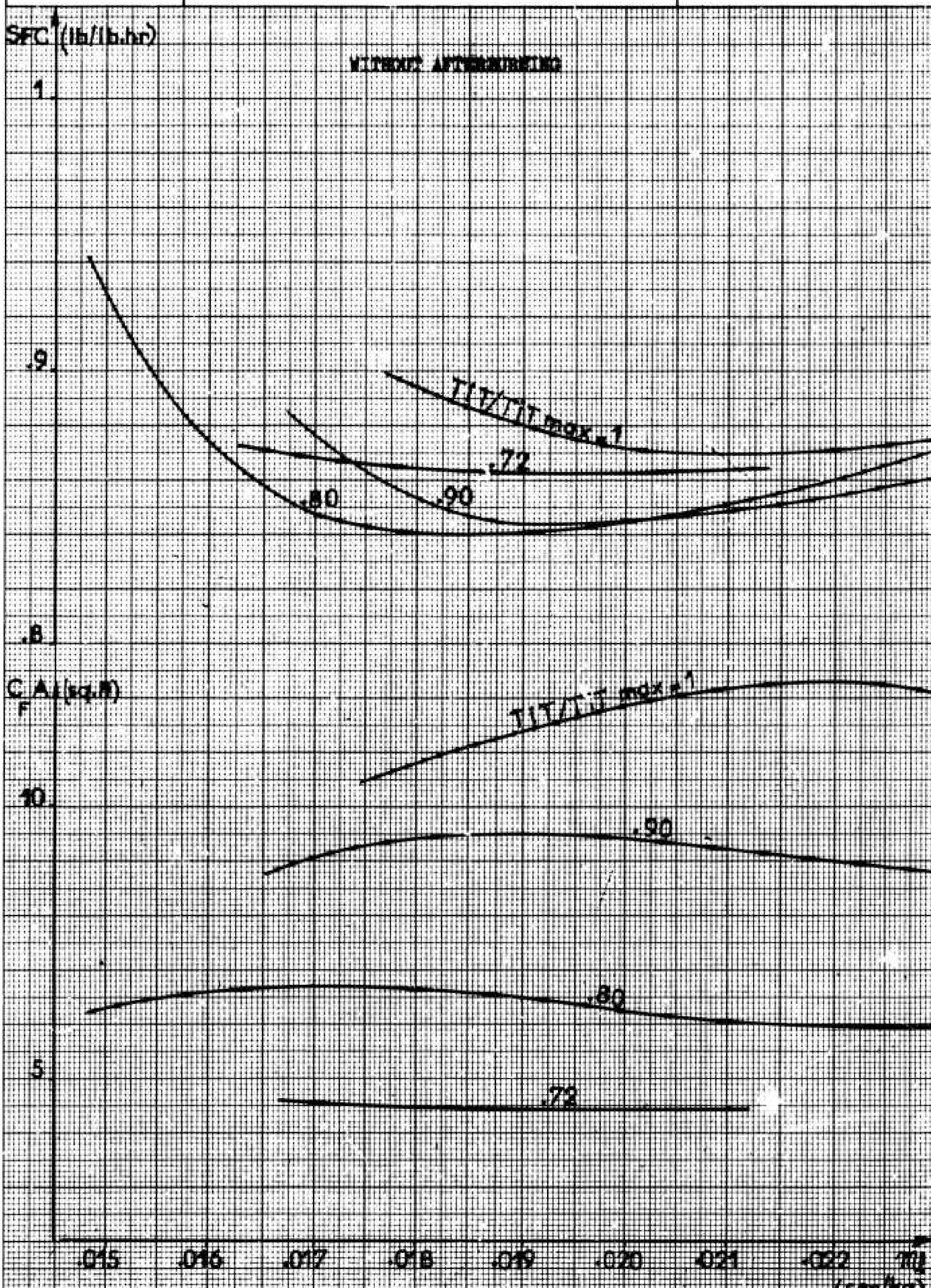
Nord-Aviation	TURBOFAN OPERATION Mo = 1.5 Z = 20 000 ft	5152/NIOBE IV/34/Z Figure 58



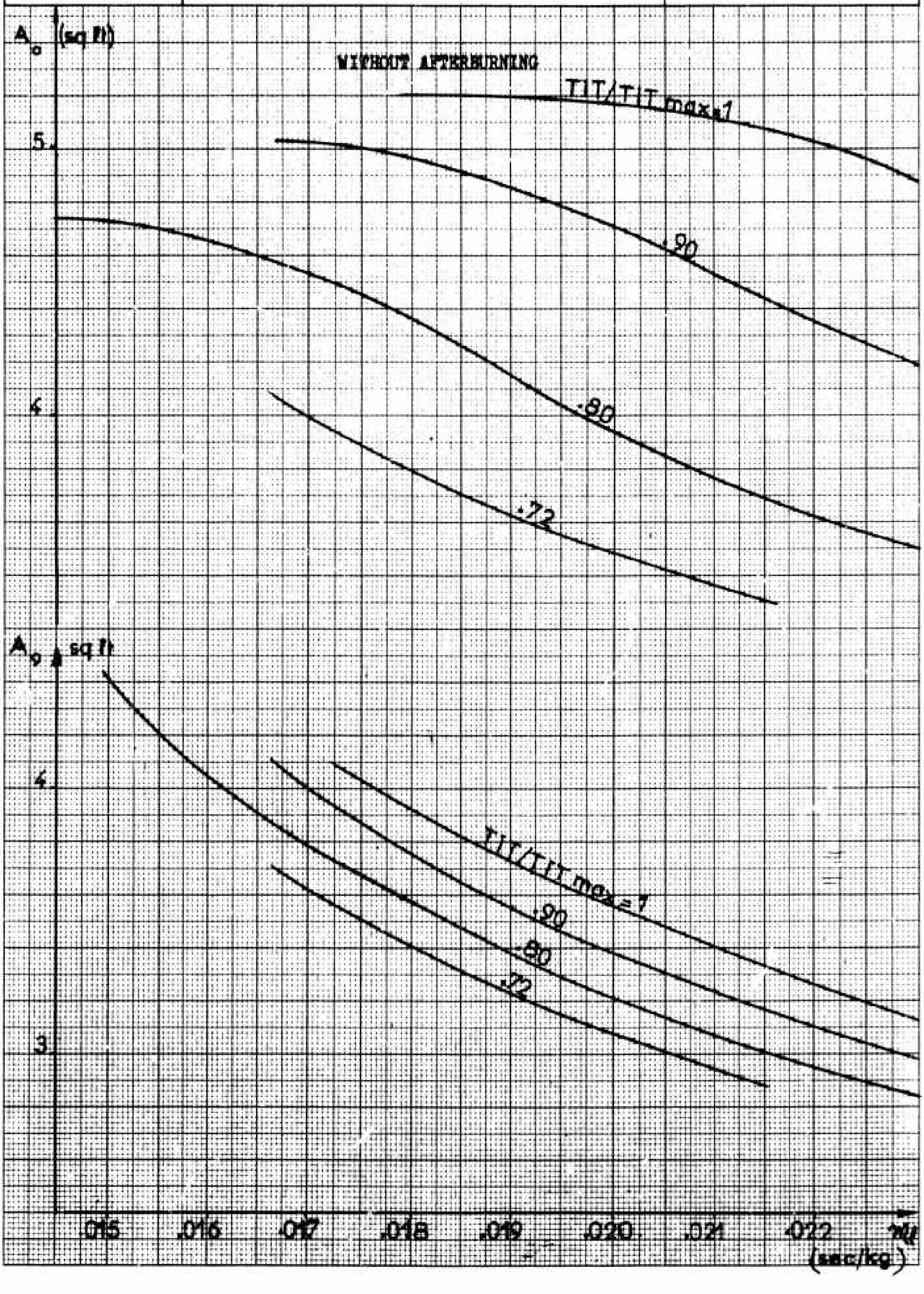
Nord-Aviation	TURBOFAN OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.5 Z = 20 000 ft	Figure 59



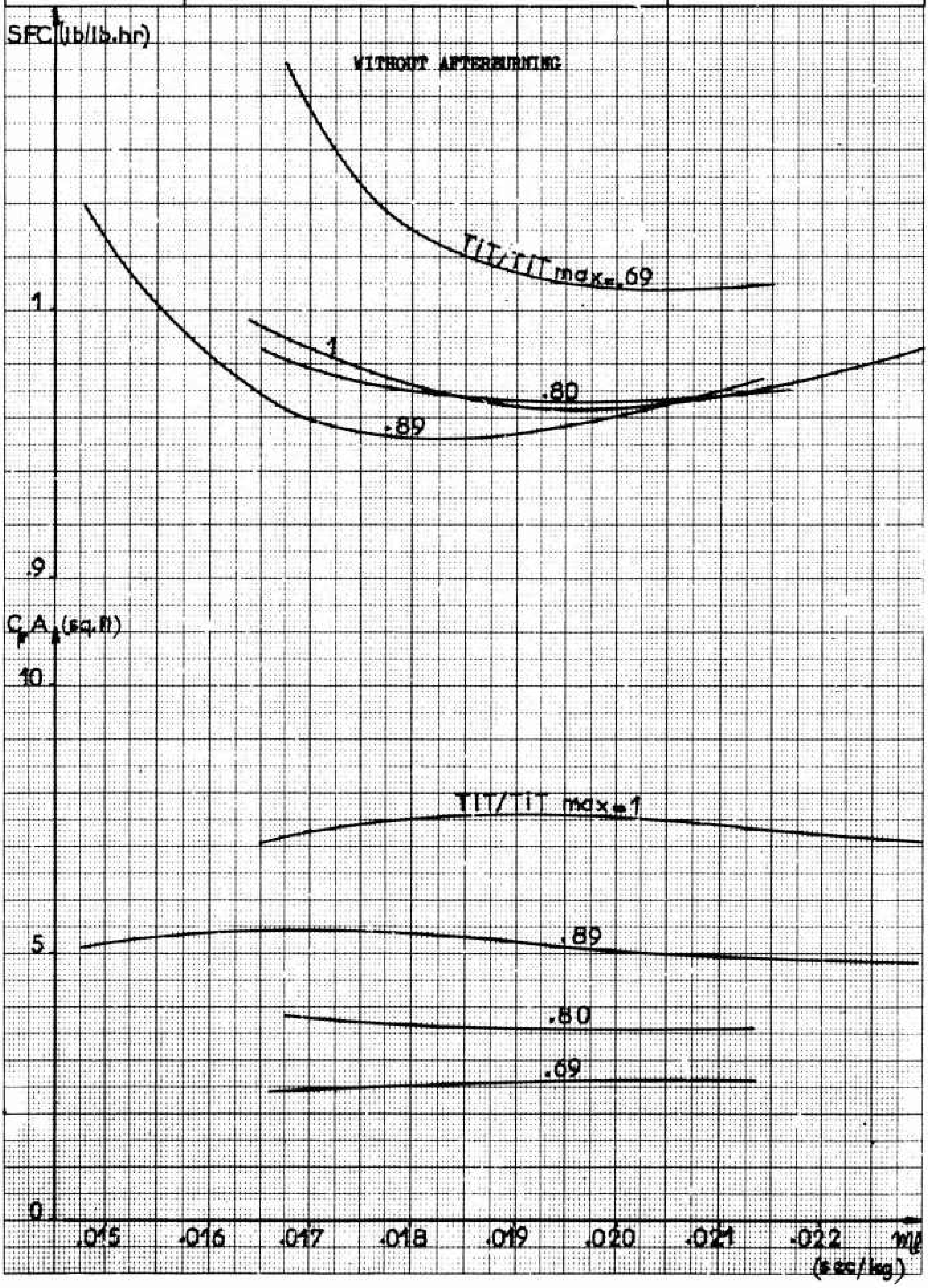
Nord-Aviation	TURBOFAN OPERATION Mo = 1 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 60



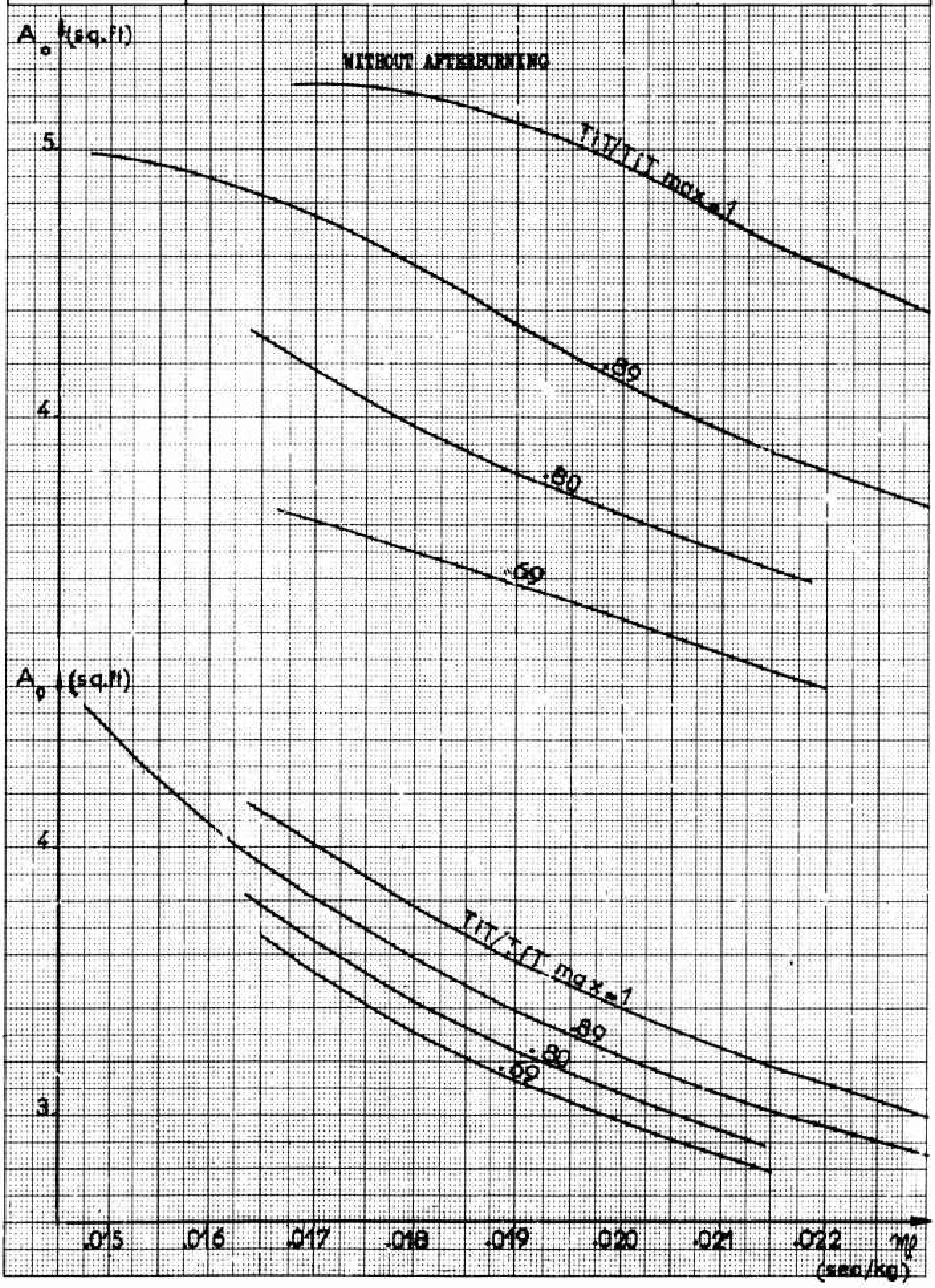
Nord-Aviation	TURBOFAN OPERATION Mo = 1 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 61



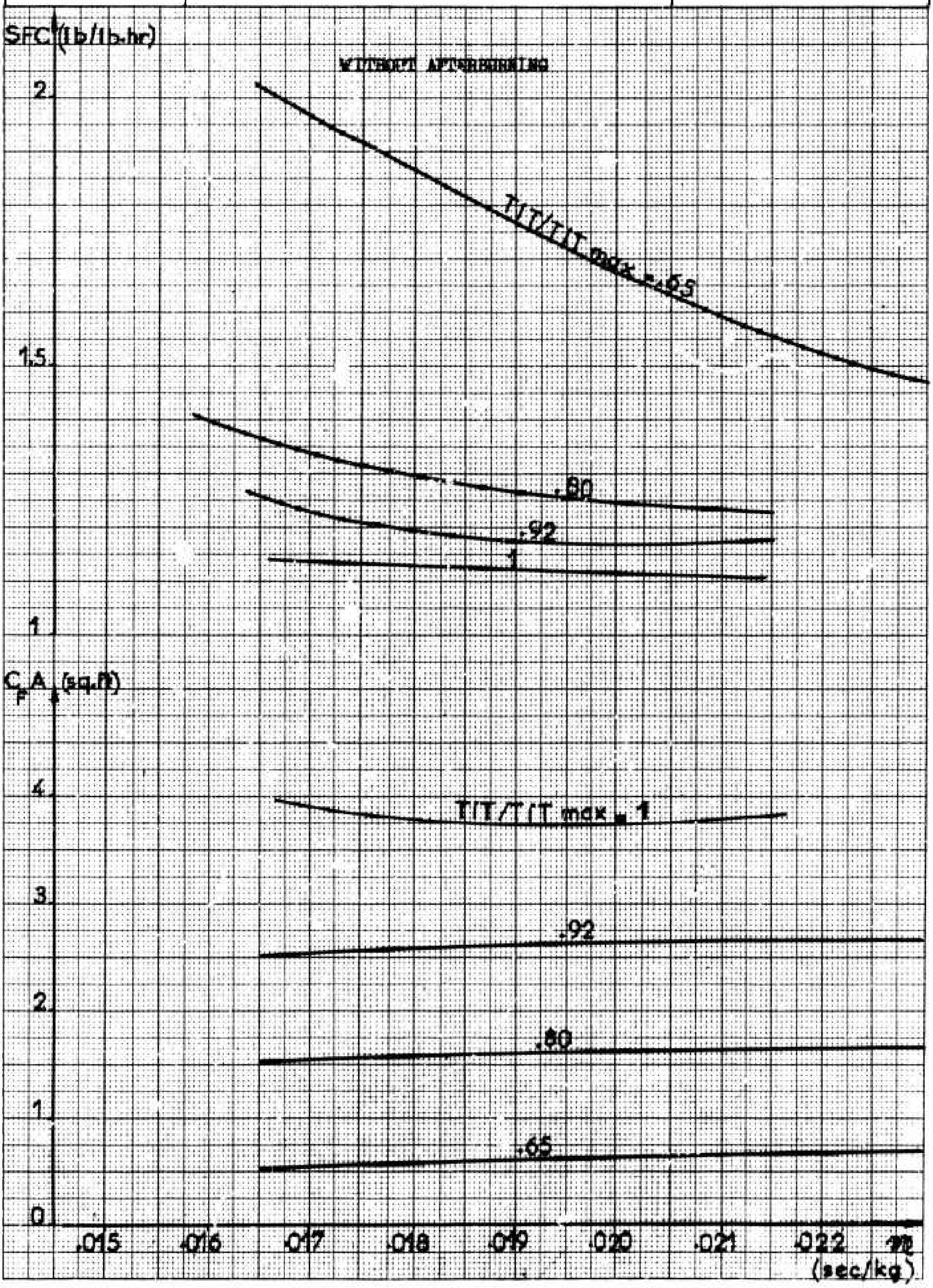
Nord-Aviation	TURBOFAN OPERATION Mo = 1.29 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 62



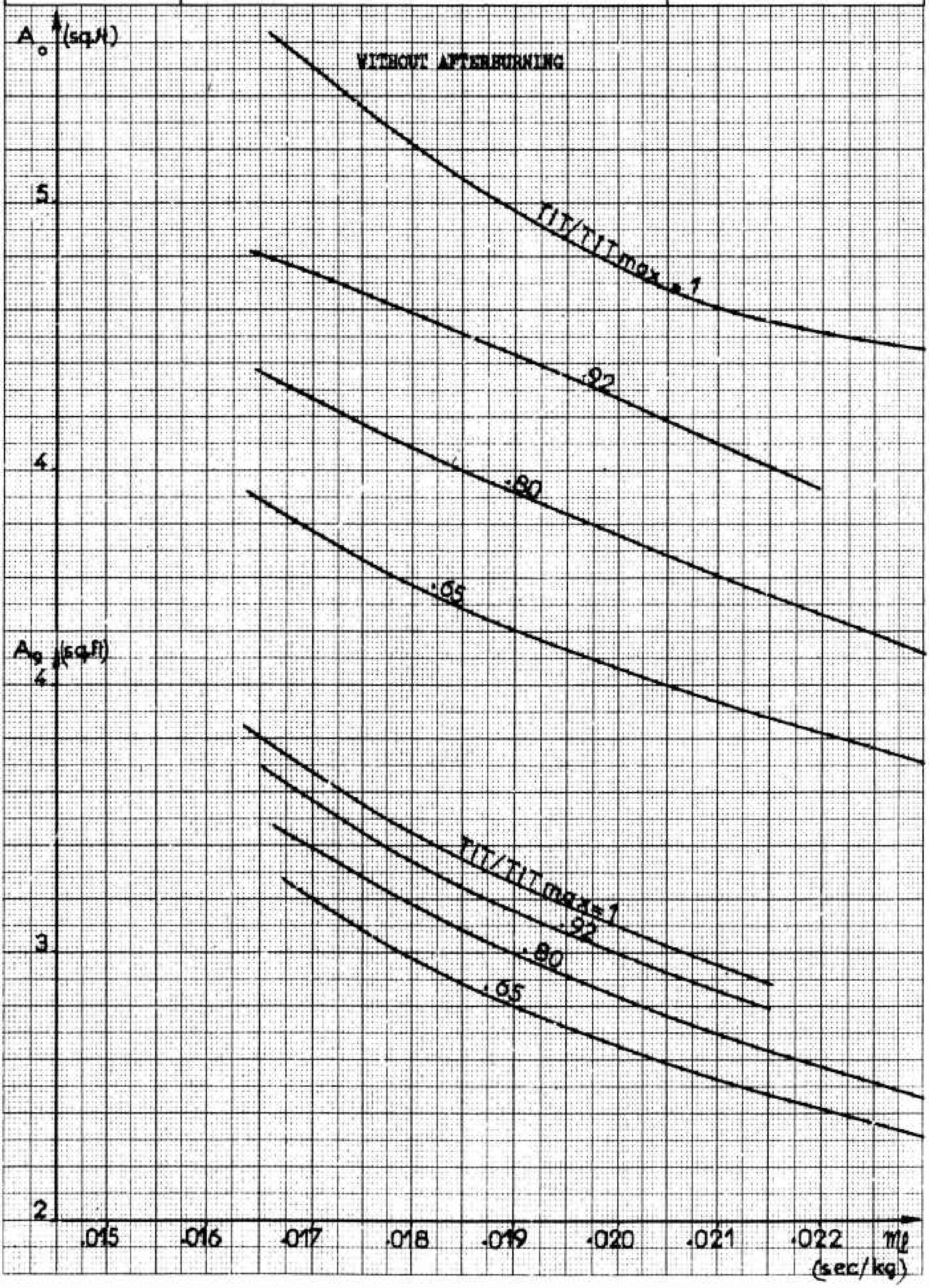
Nord-Aviation	TURBOFAN OPERATION Mo = 1.29 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 63



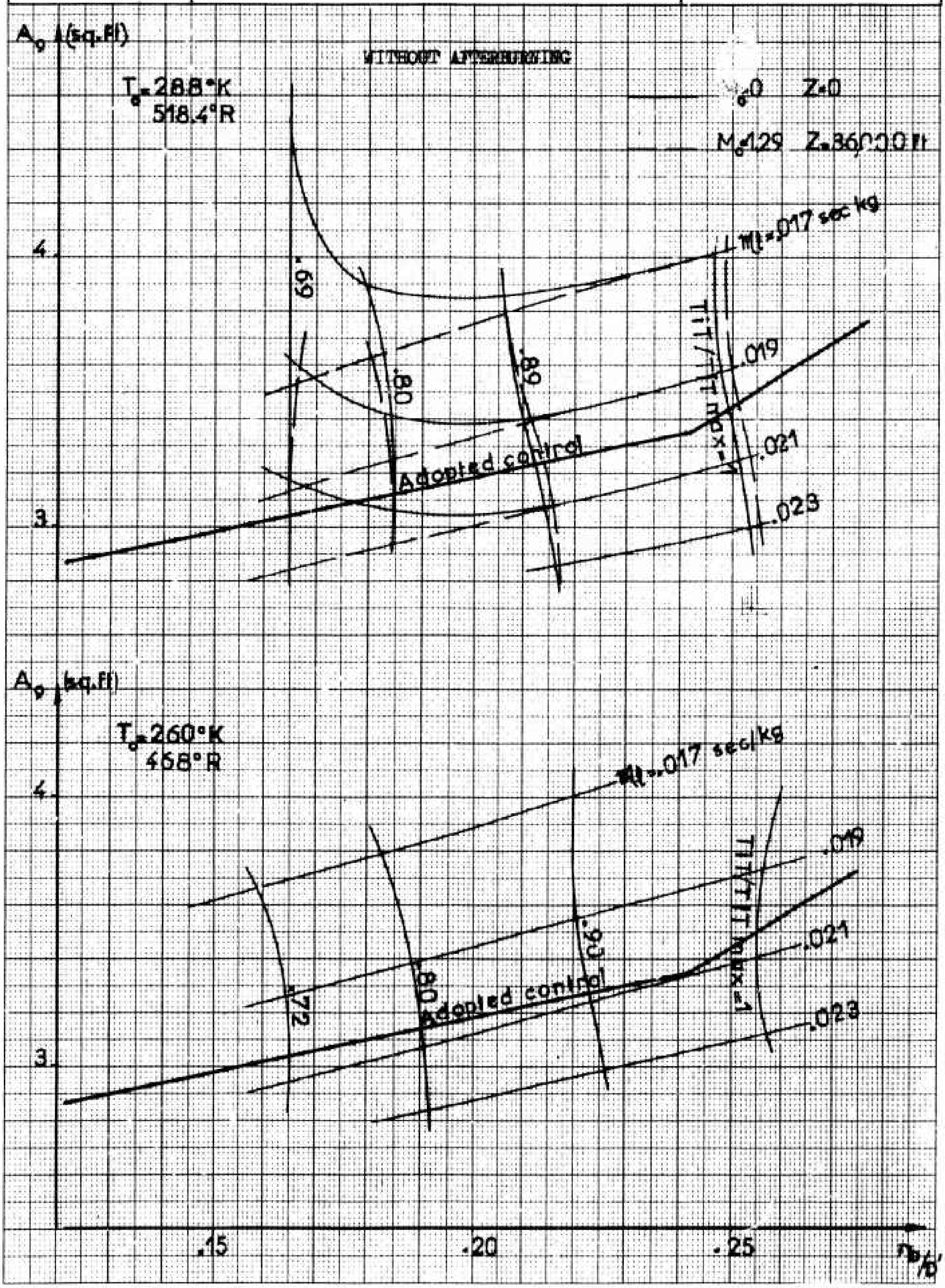
Nord-Aviation	TURBOFAN OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 64



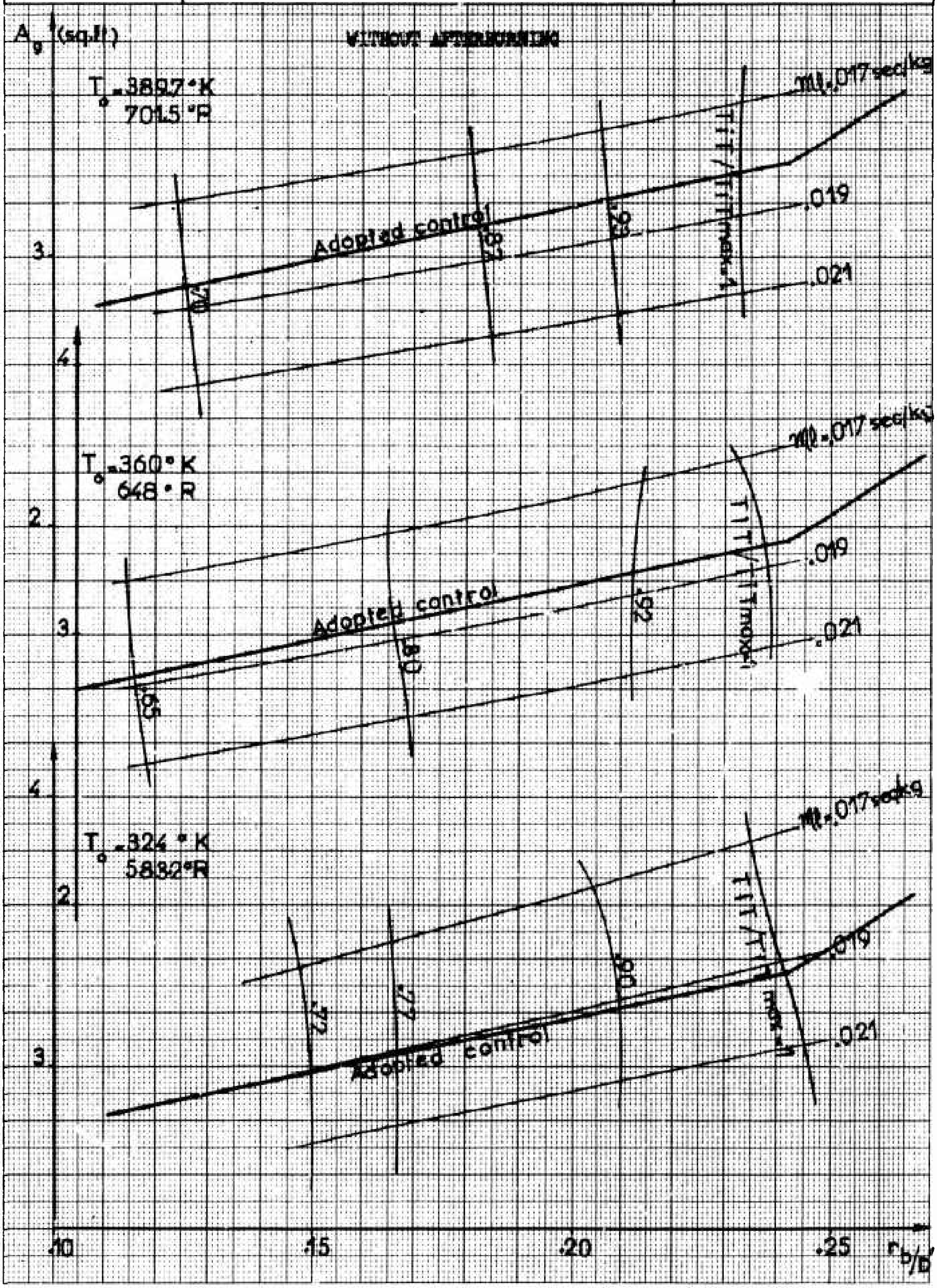
Nord-Aviation	TURBOFAN OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 65



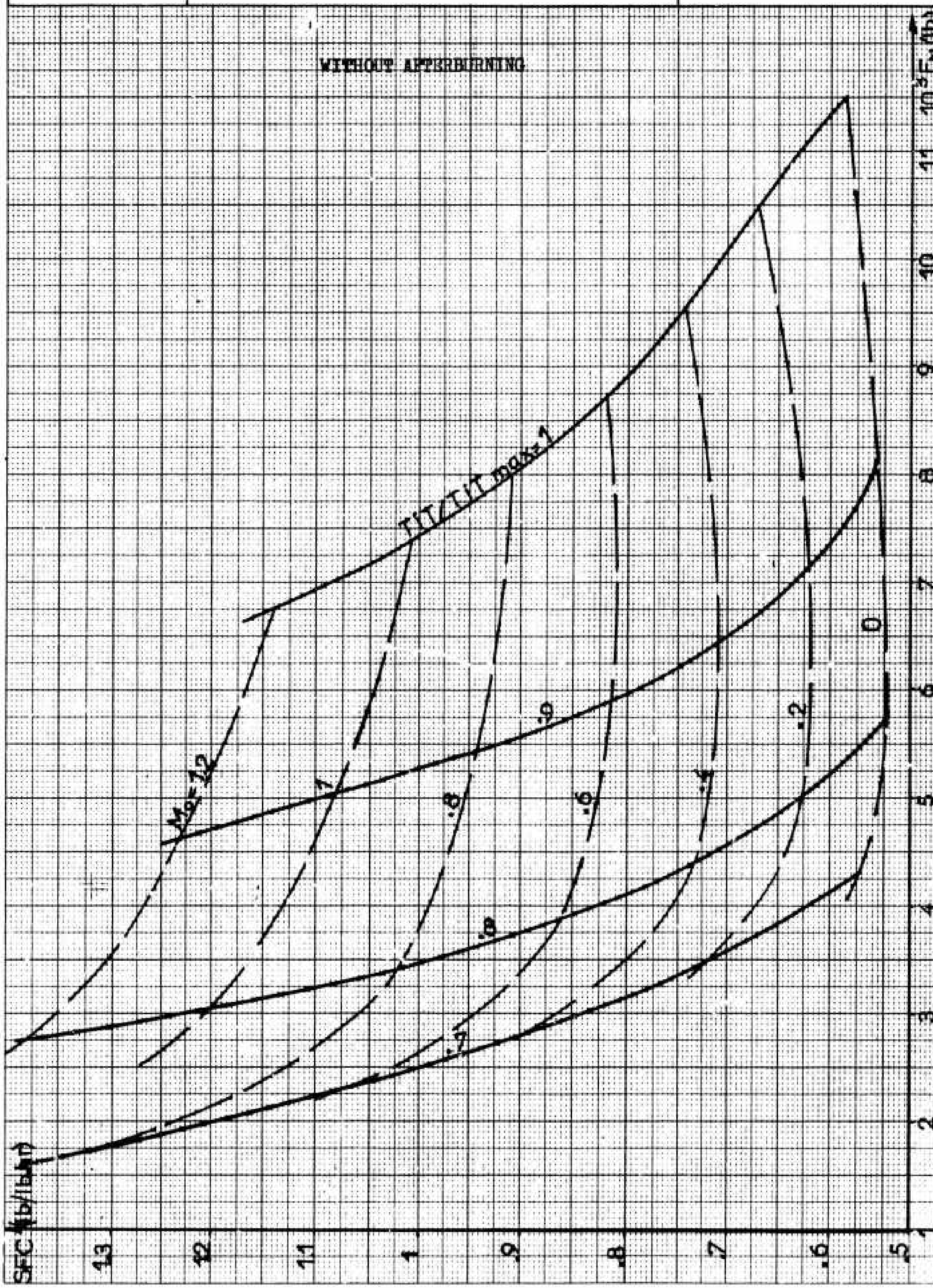
Nord-Aviation	TURBOFAN OPERATION Exit nozzle throat area	5152/NIOBE IV/34/Z FIGURE 66



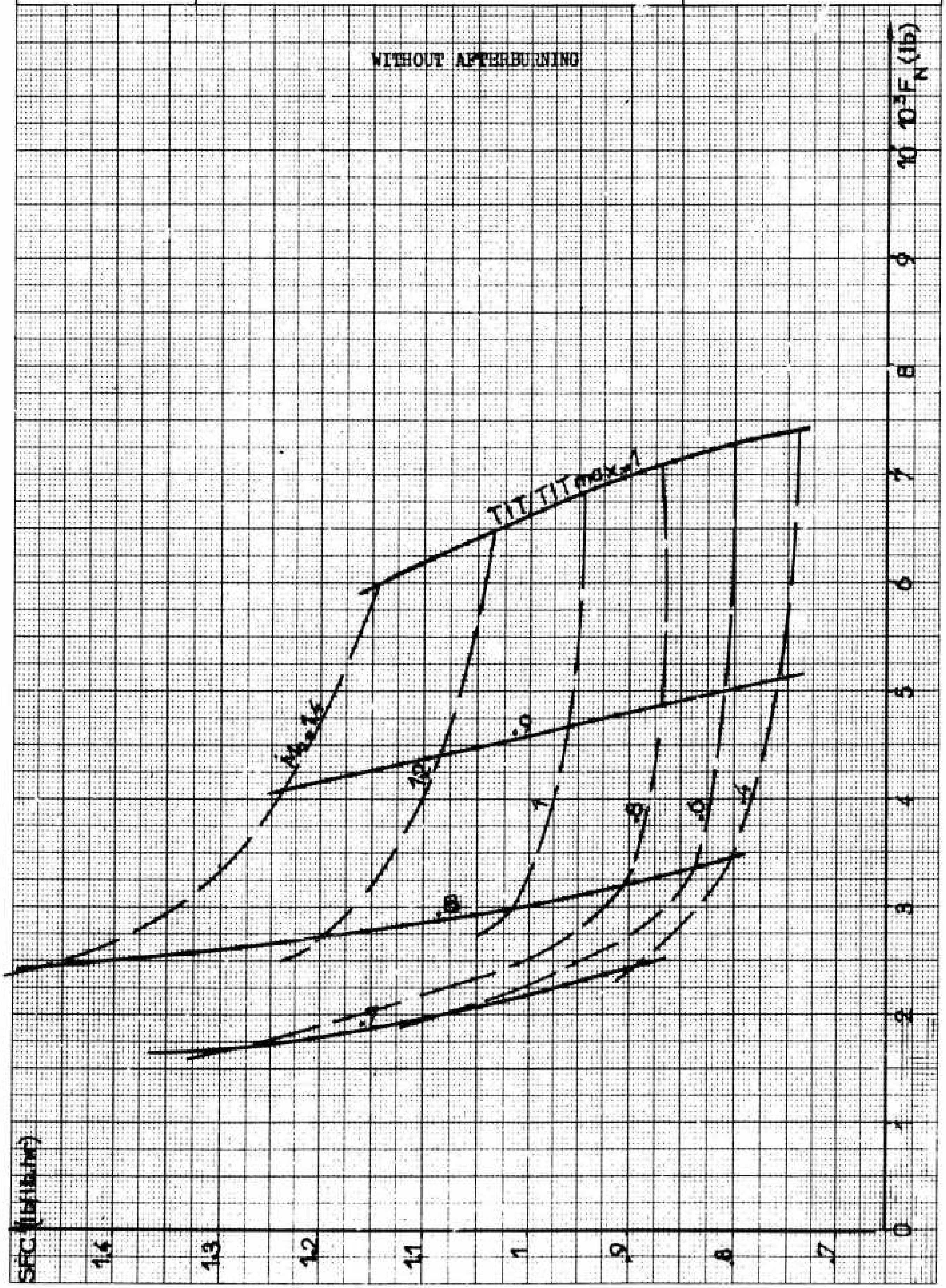
Nord-Aviation	TURBOFAN OPERATION Exit nozzle throat area	5152/NIOBE IV/34/Z Figure 67



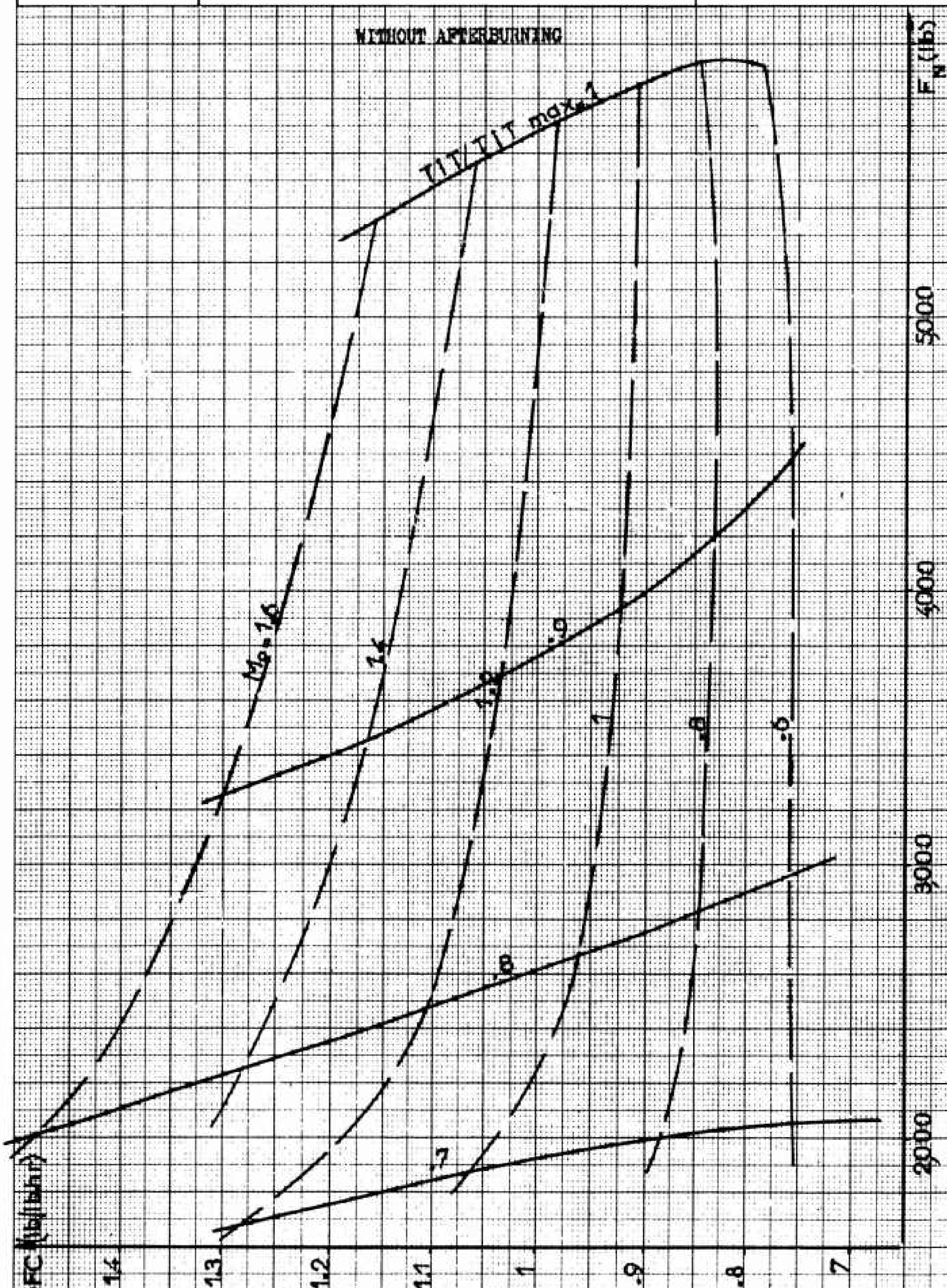
Nord-Aviation	TURBOFAN OPERATION Z = 0 ft	5152/NIOBE IV/34/Z Figure 68



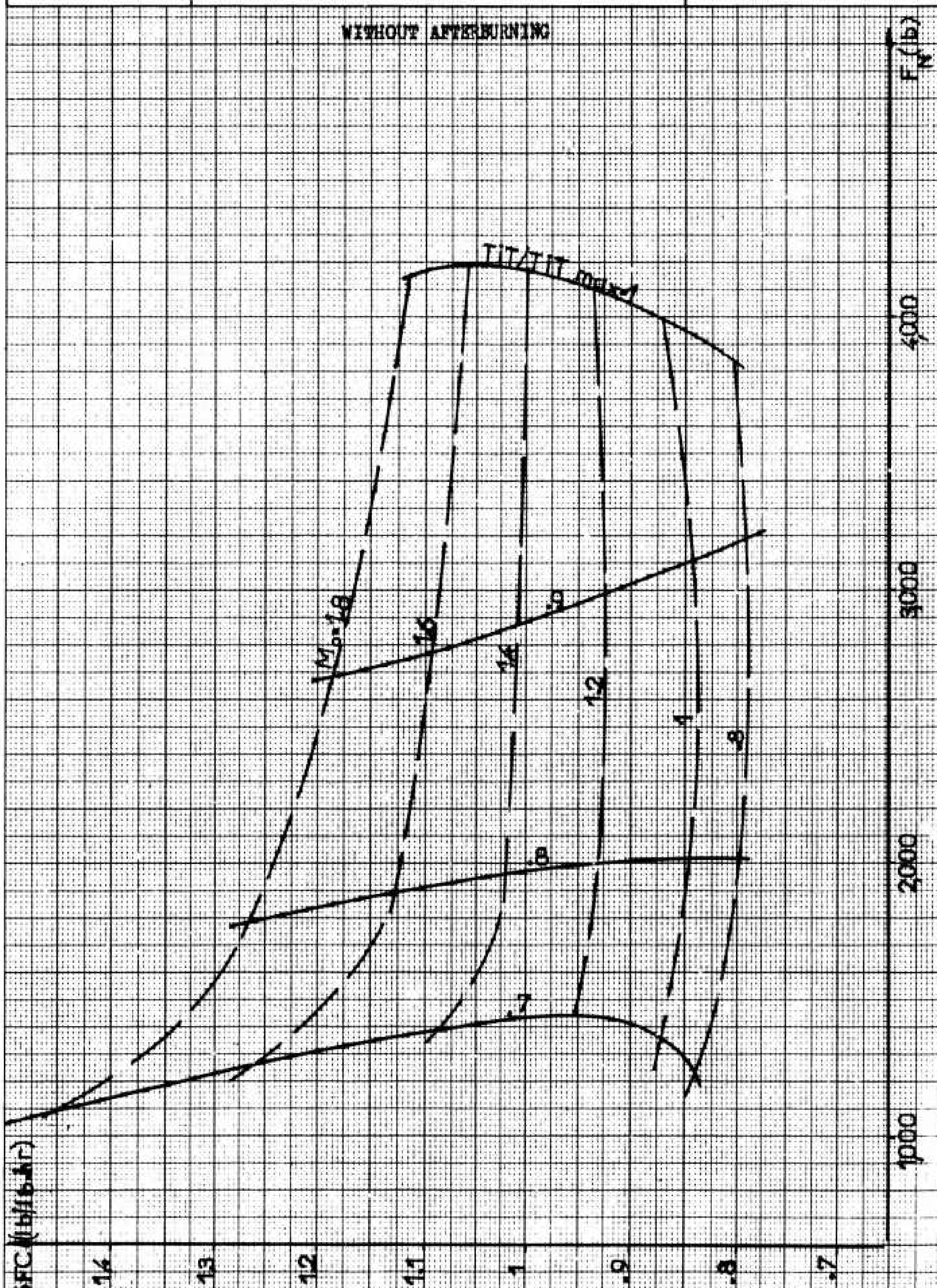
Nord-Aviation	TURBOFAN OPERATION Z = 10 000 ft	5152/NIOBE IV/34/Z **Figure** 69



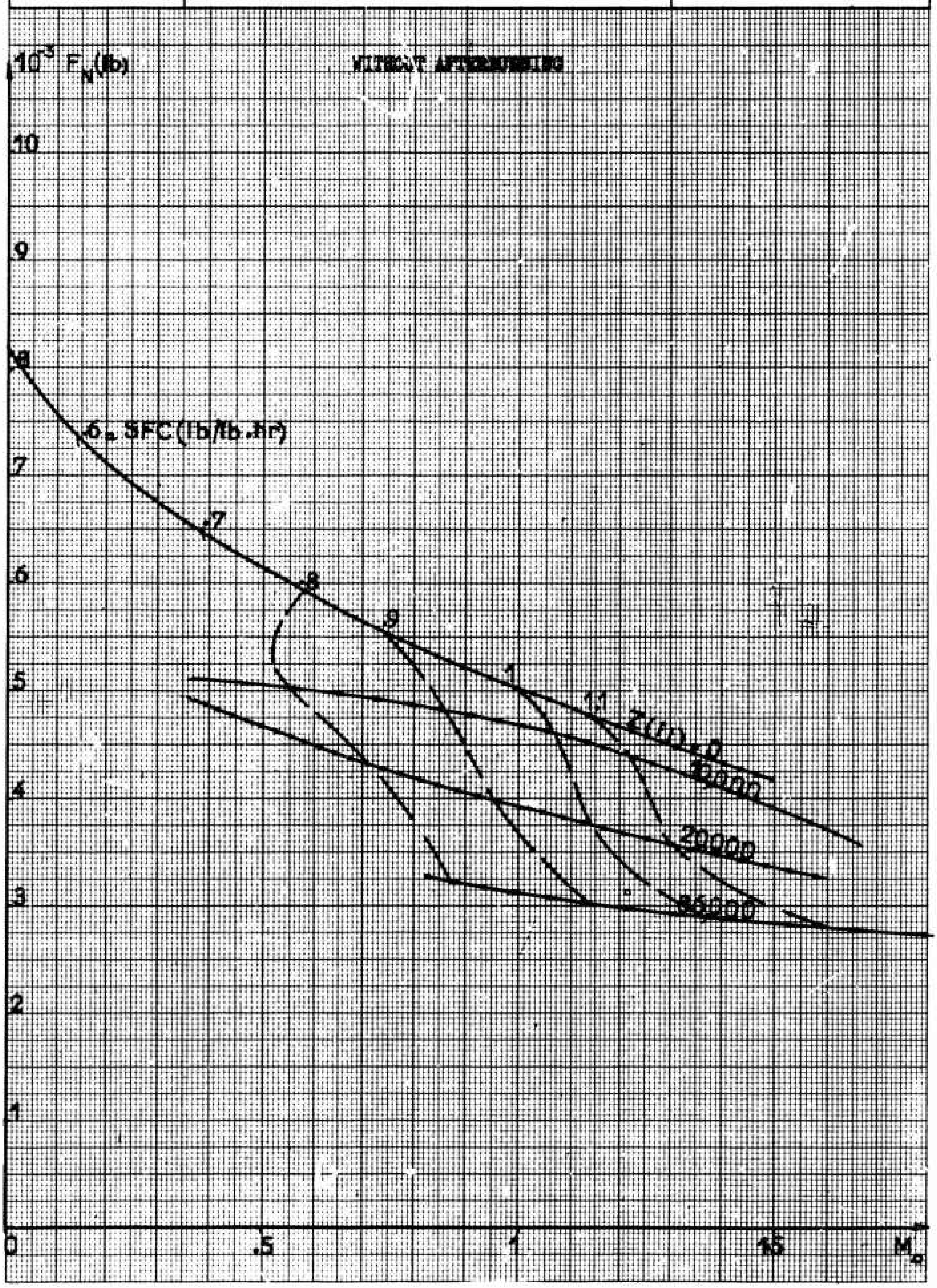
Nord-Aviation	TURBOFAN OPERATION Z = 20 000 ft	5152/NIOBE IV/34/Z **Figure 70**



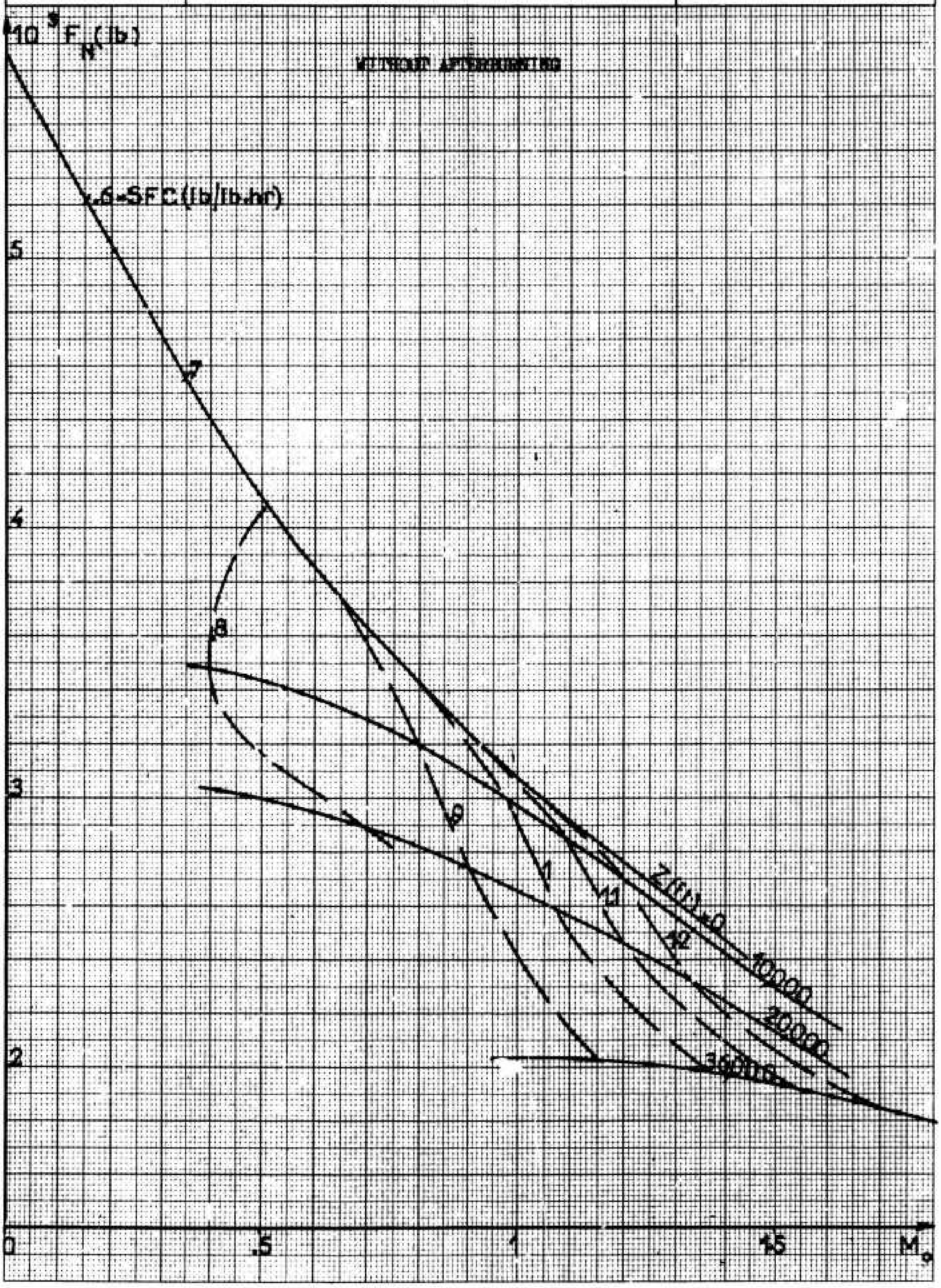
Nord-Aviation	TURBOFAN OPERATION Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 71



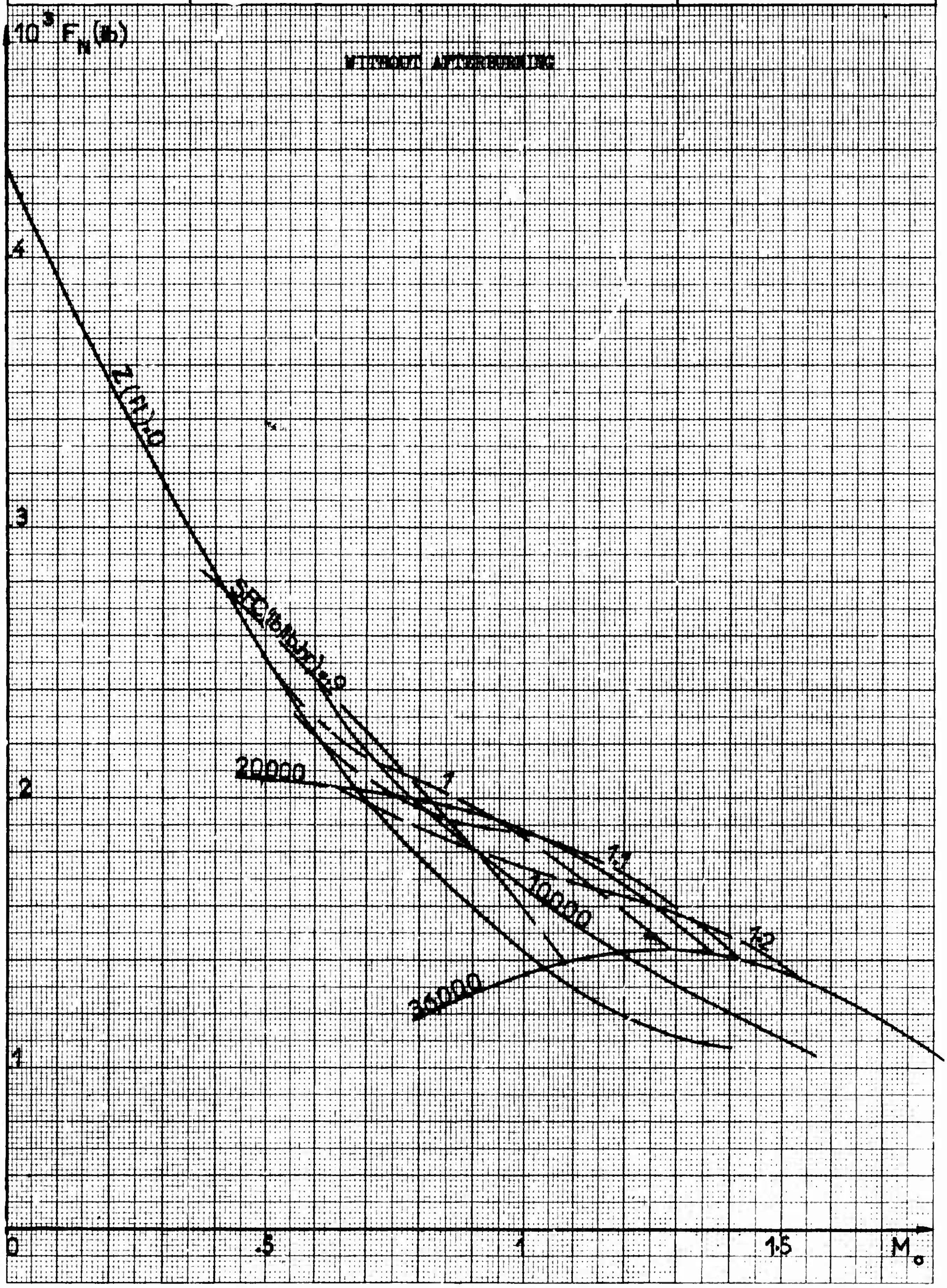
Nord-Aviation	TURBOFAN OPERATION T.I.T = 0.9 T.I.T. max	5152/NIOBE IV/34/Z Figure 72



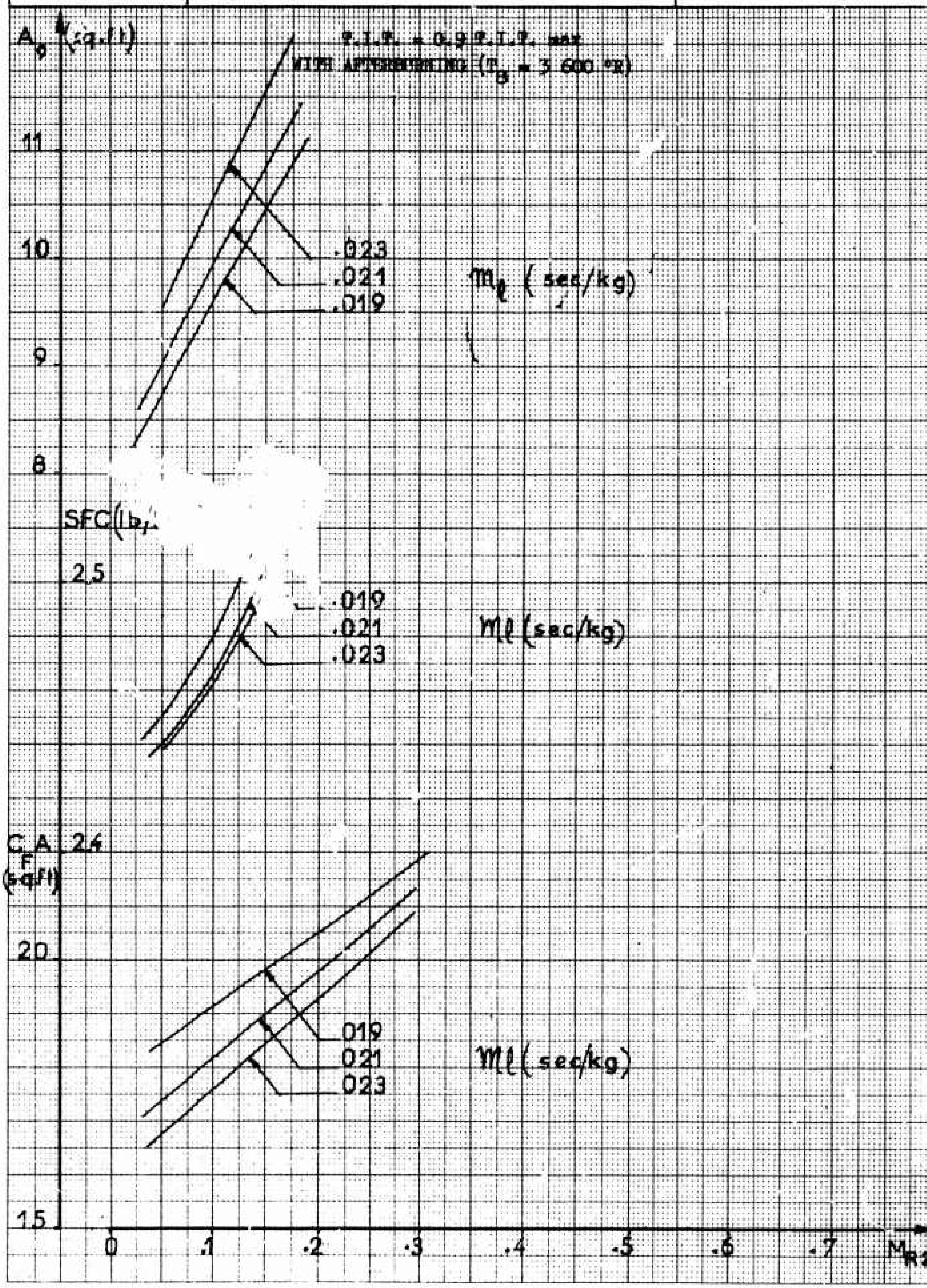
Nord-Aviation	TURBOFAN OPERATION T.I.T. = 0.8 T.I.T. max	5152/NIOBE IV/34/Z Figure 73



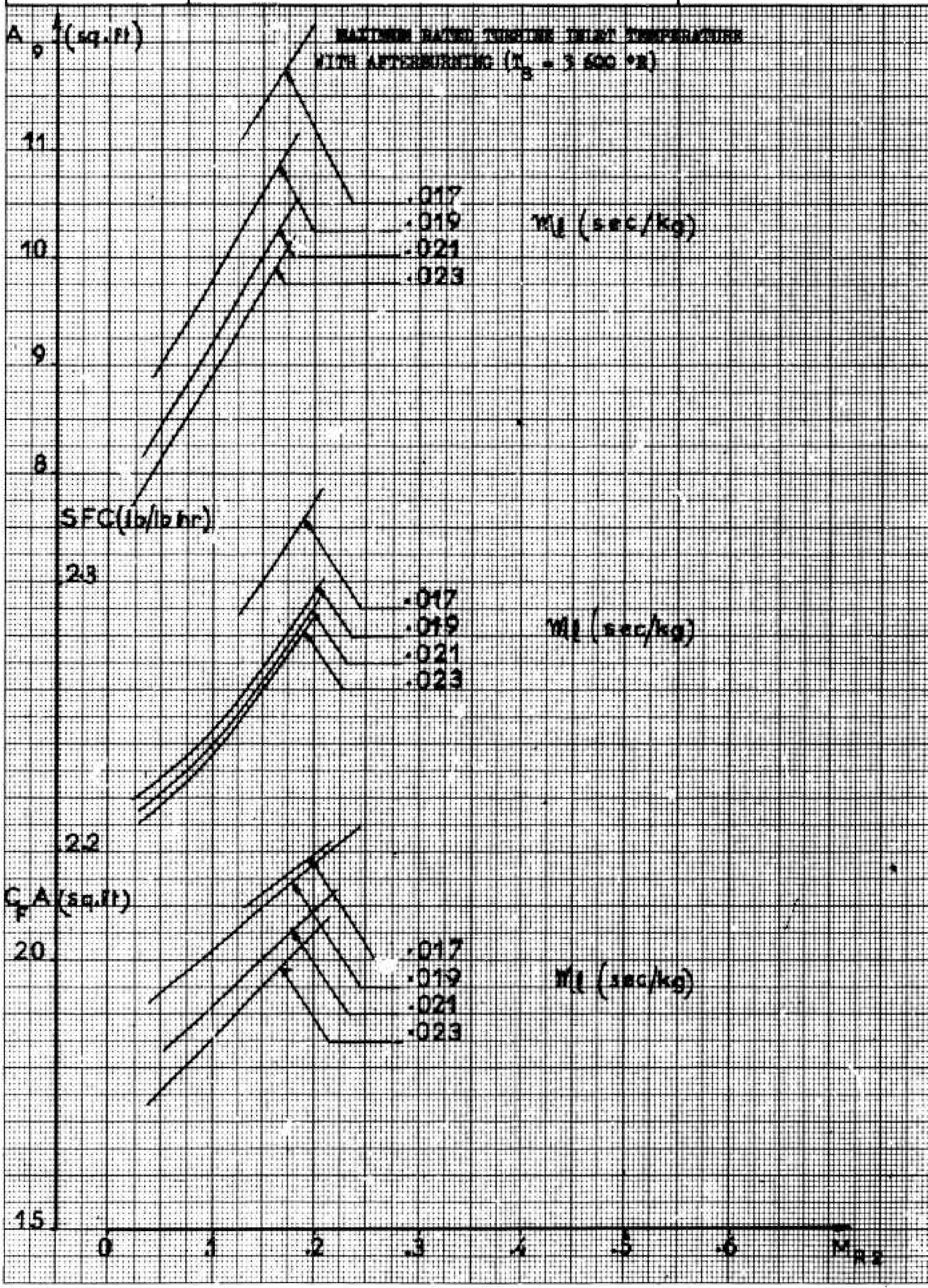
Nord-Aviation	TURBOFAN OPERATION T.I.T. = 0.7 T.I.T. max	5152/NIOBE IV/34/Z Figure 74



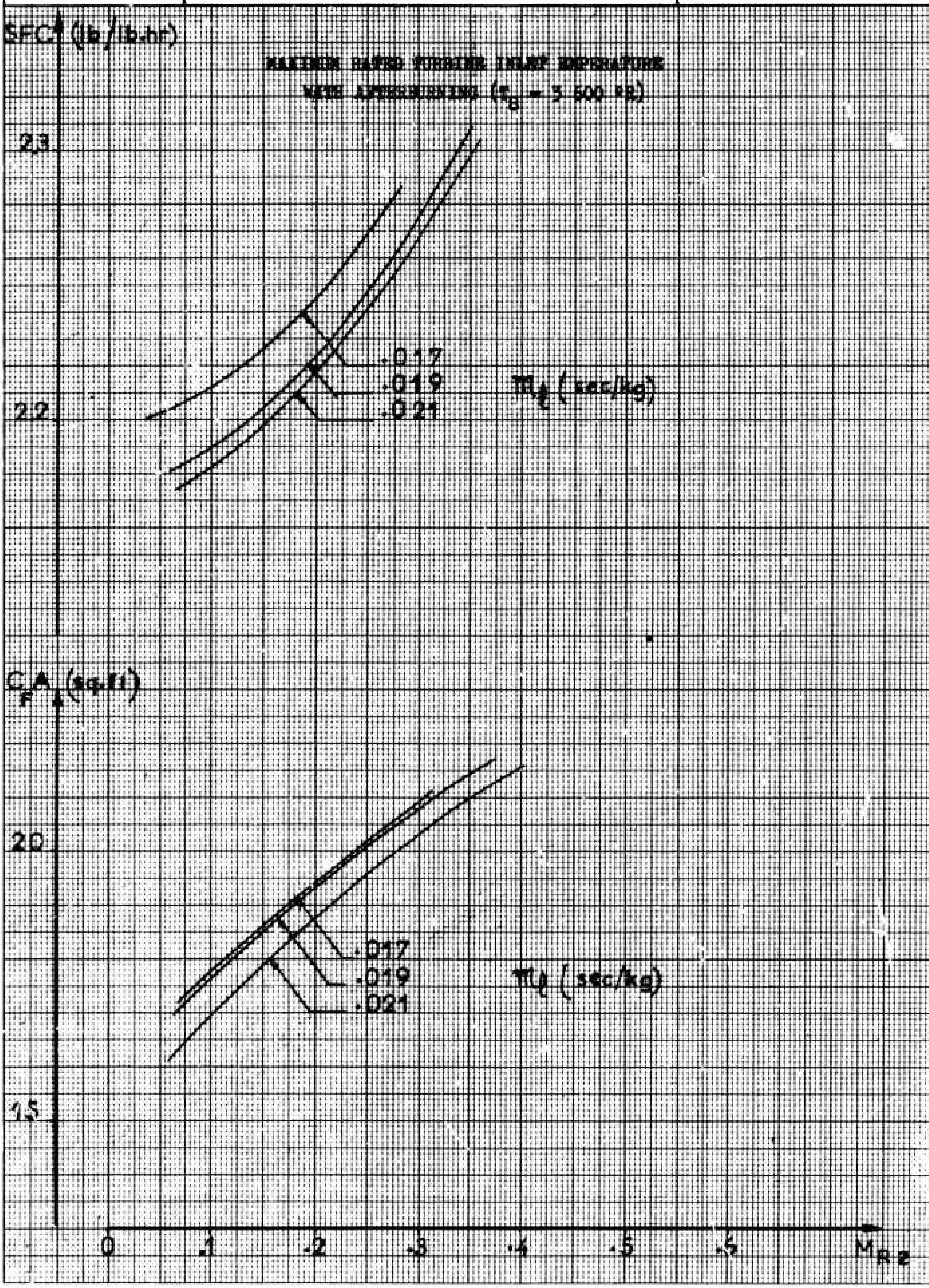
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 1.575 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 75



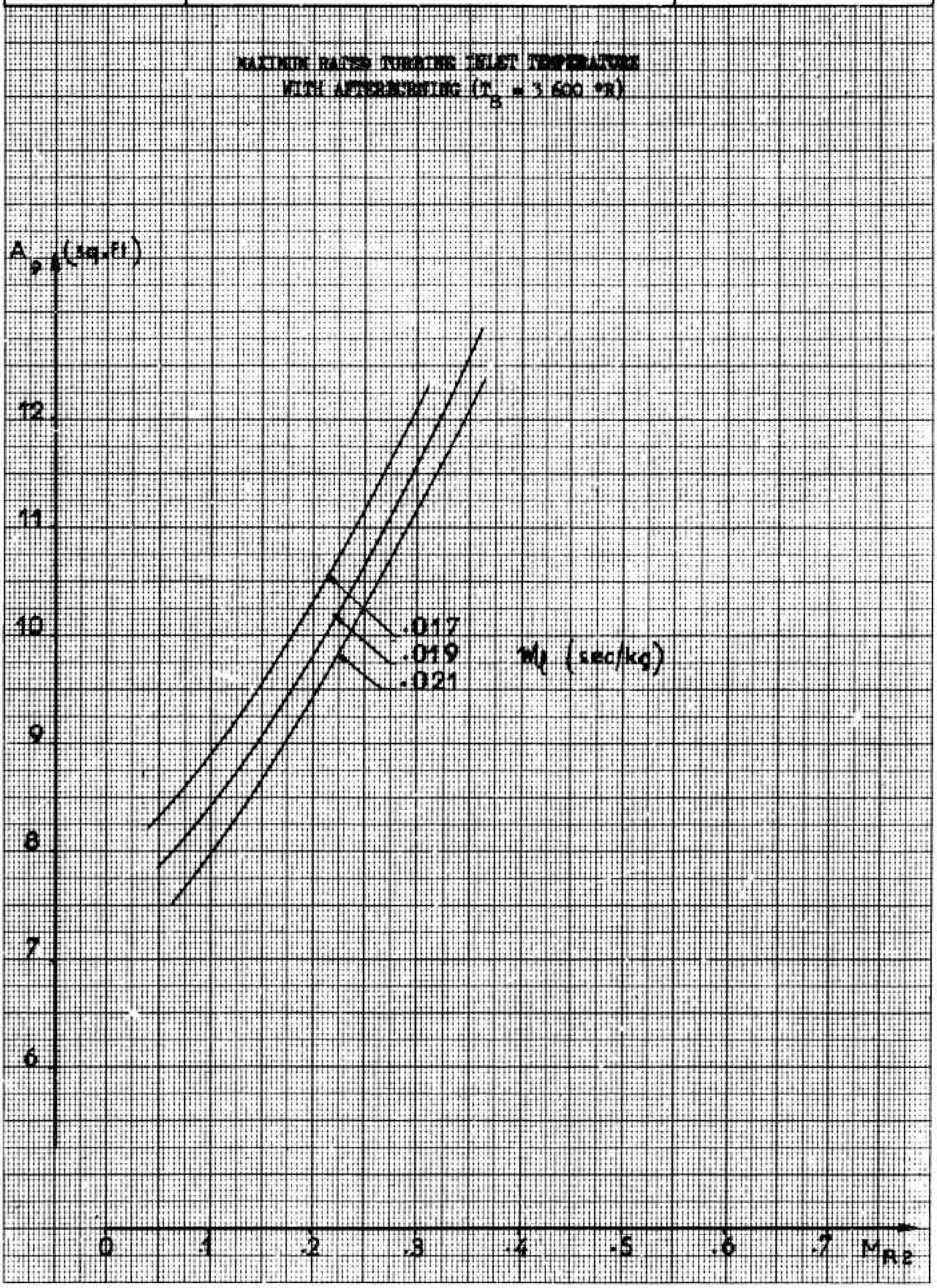
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 76



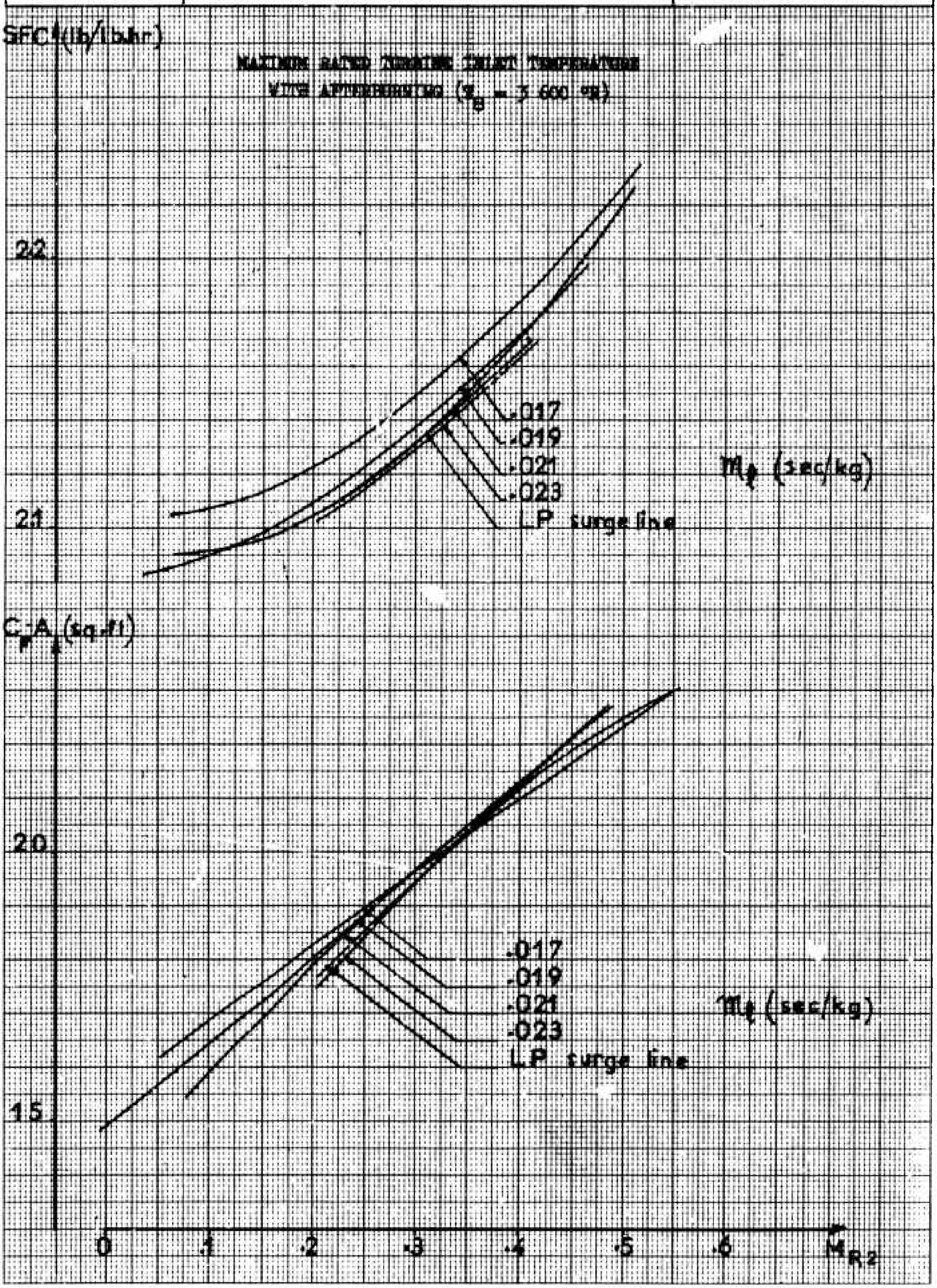
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 77



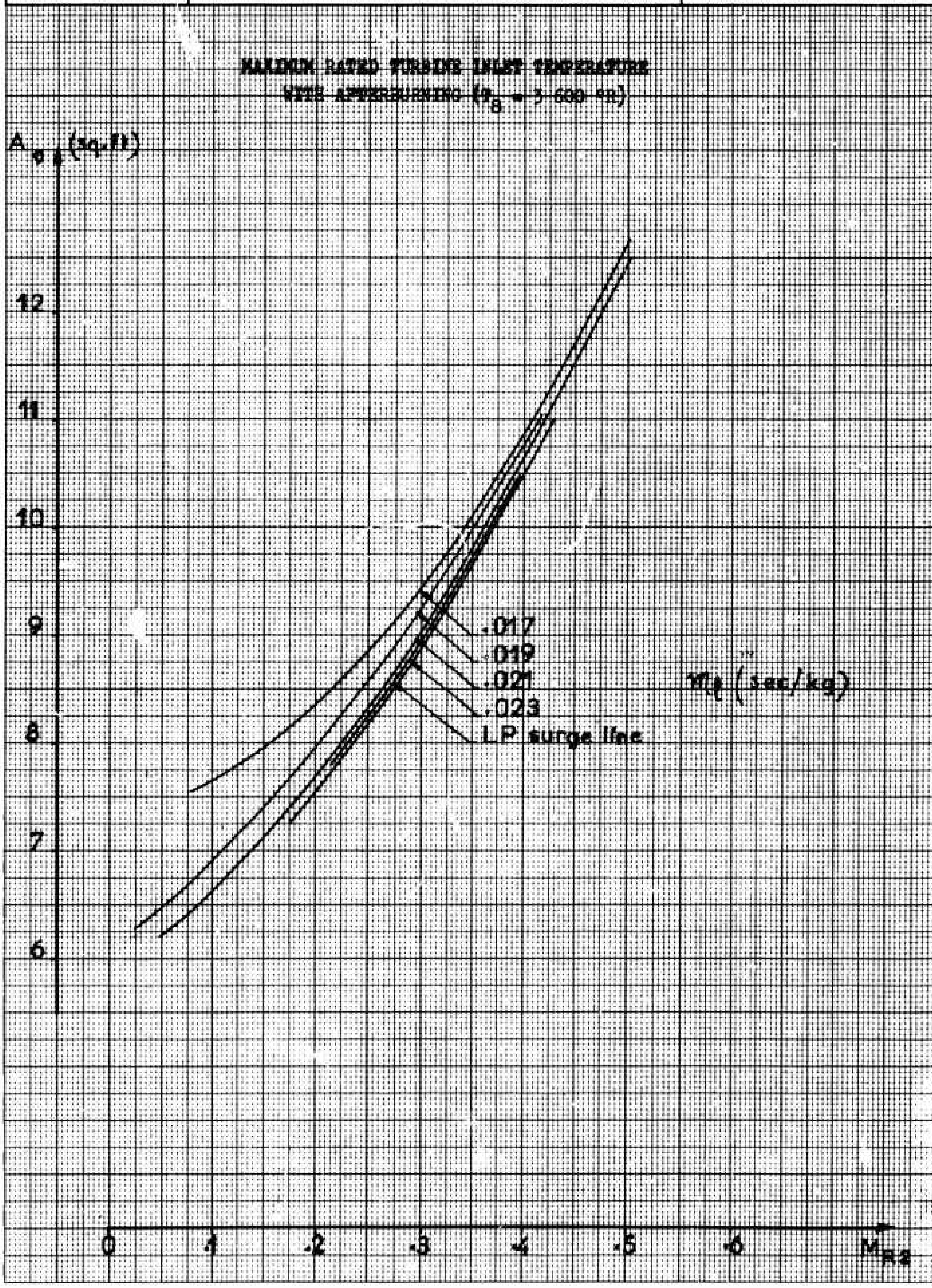
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 78



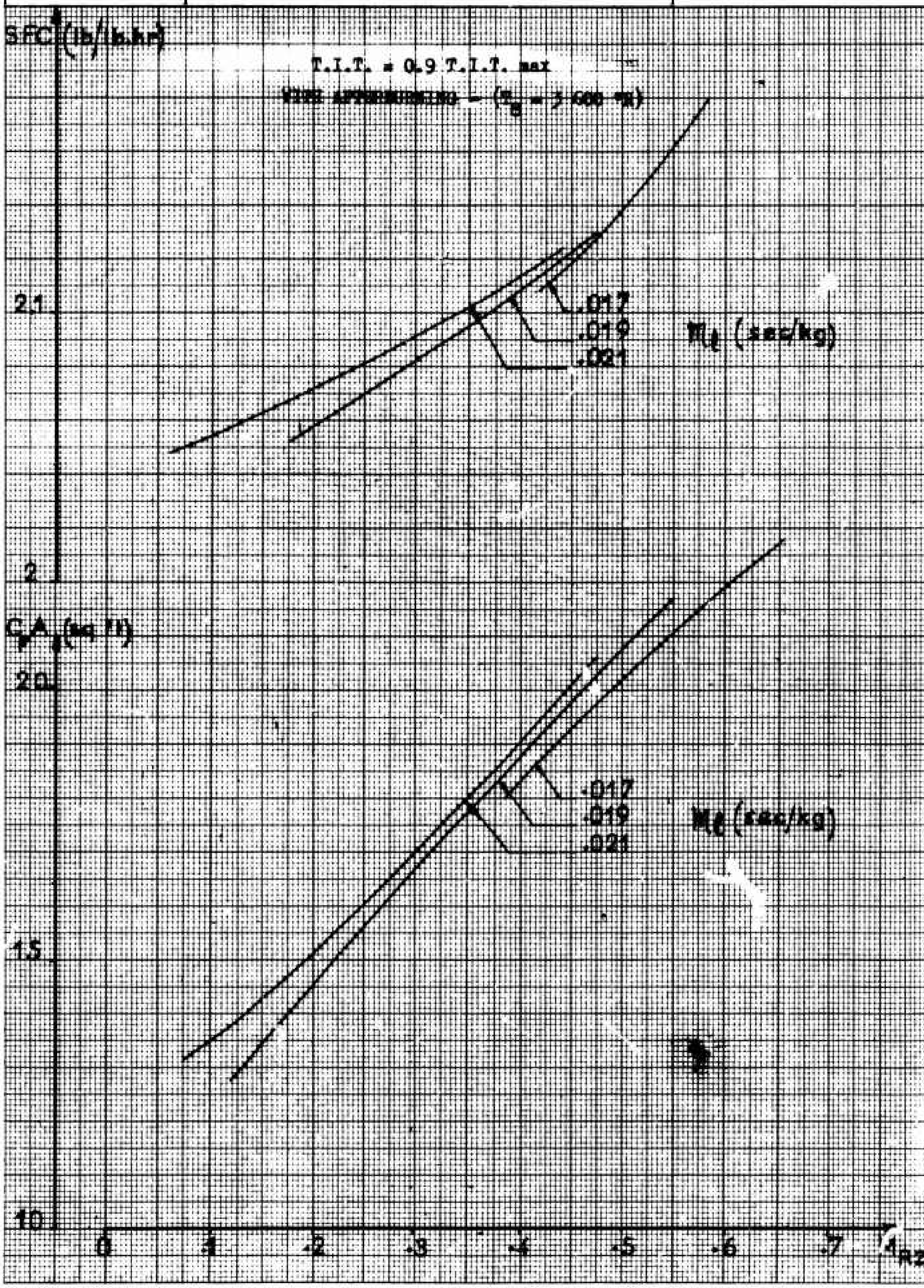
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.32 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 79



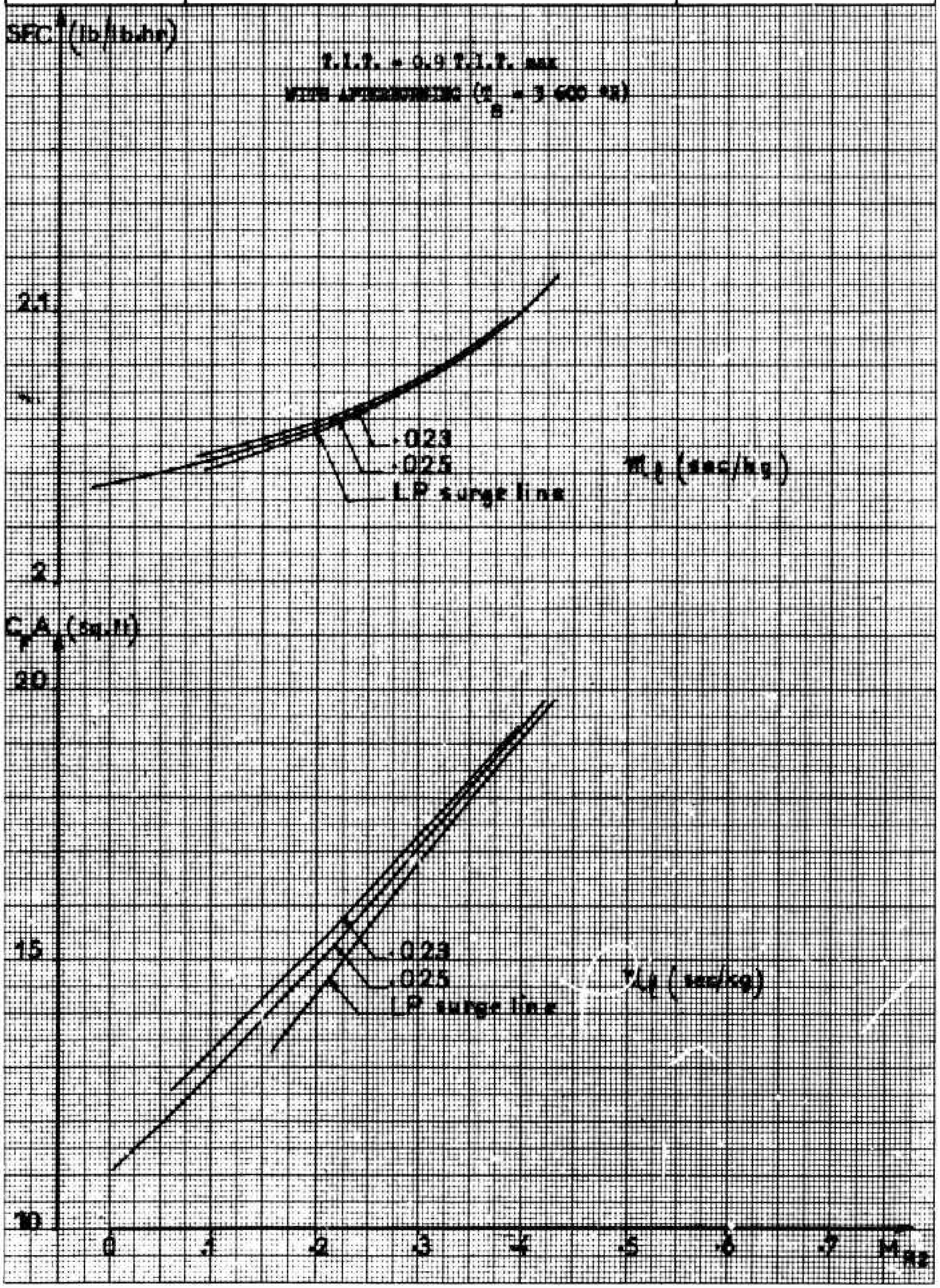
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.32 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 80



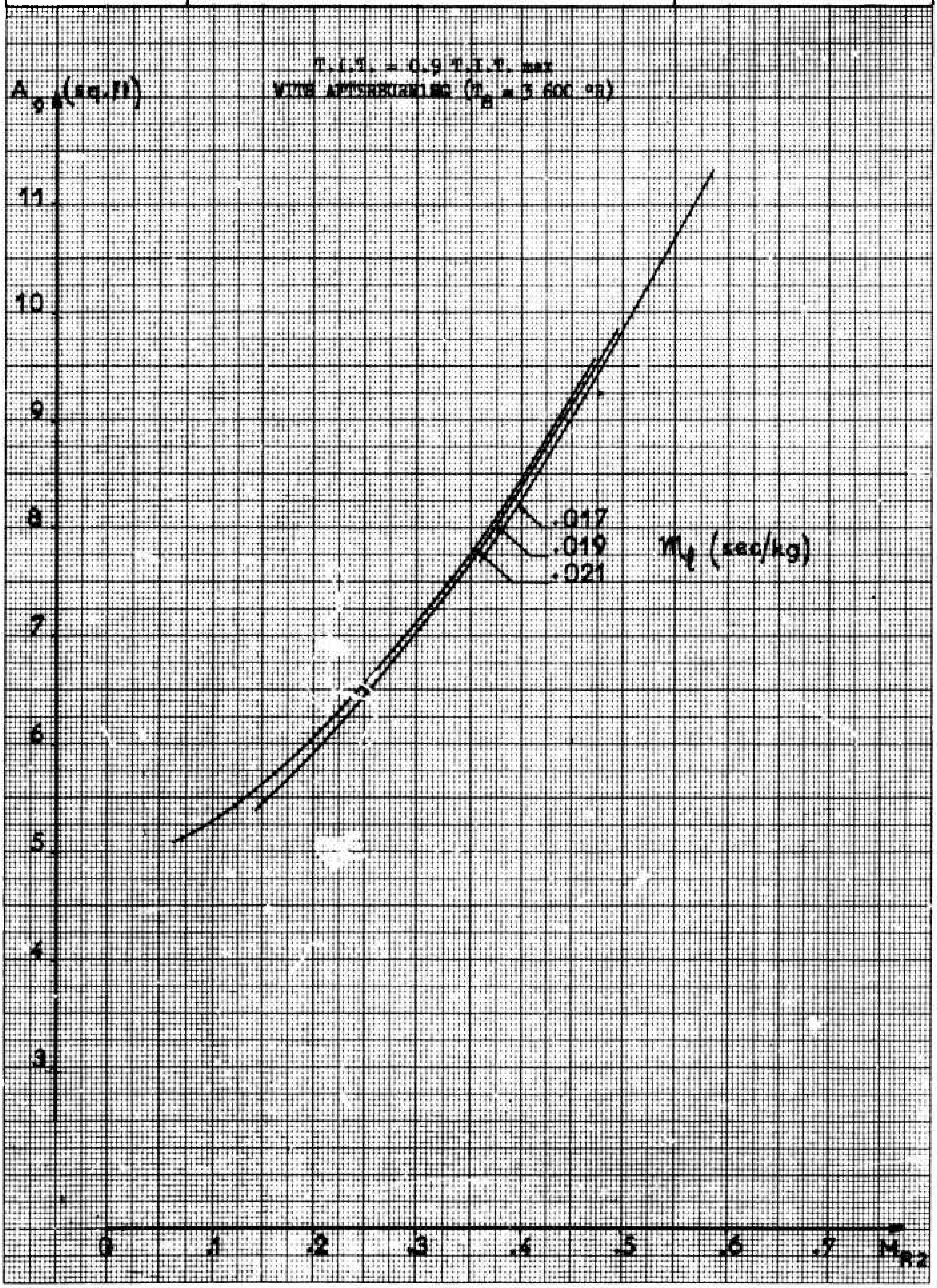
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 81



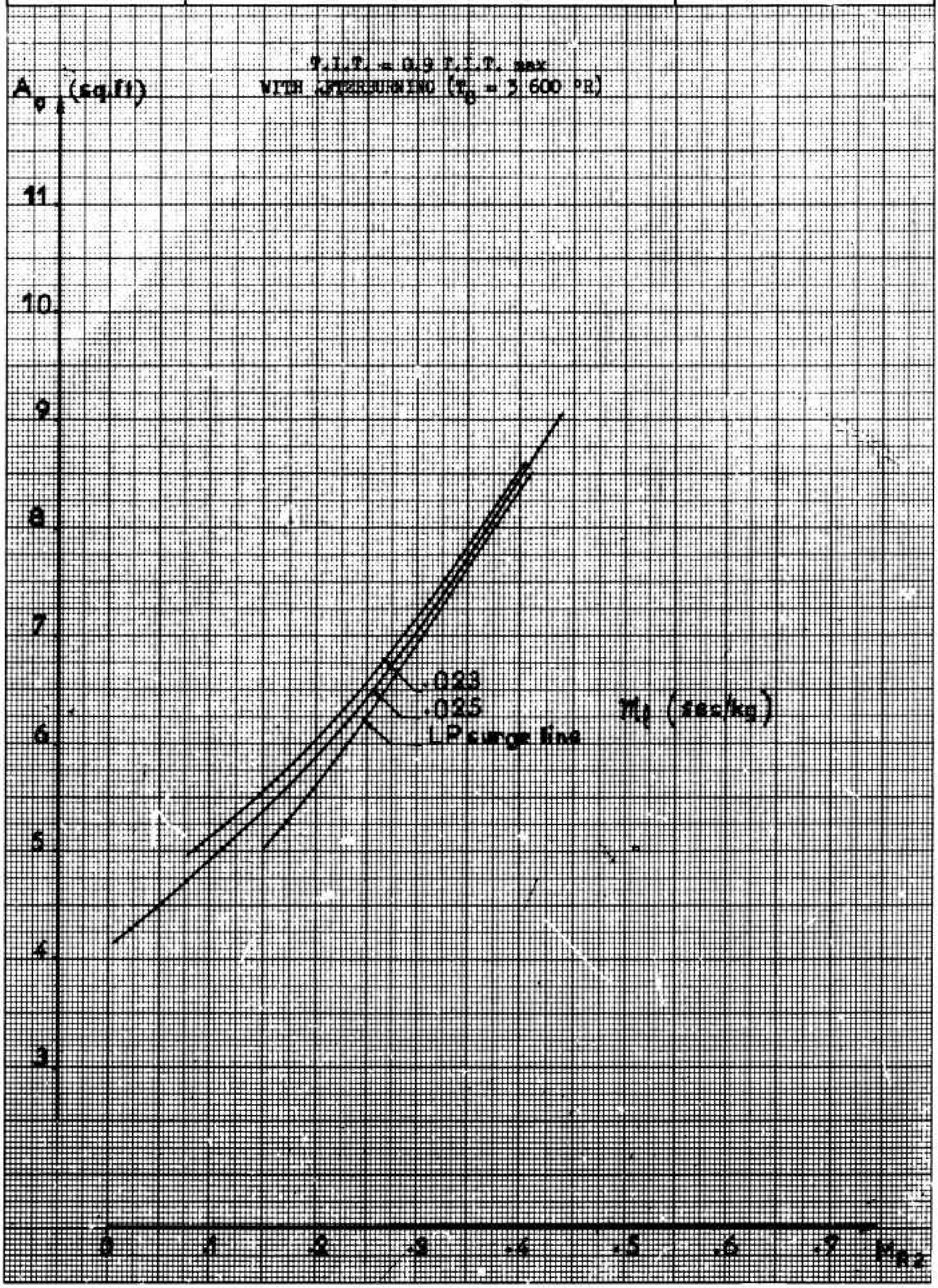
Nord-Aviation	T RBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 82



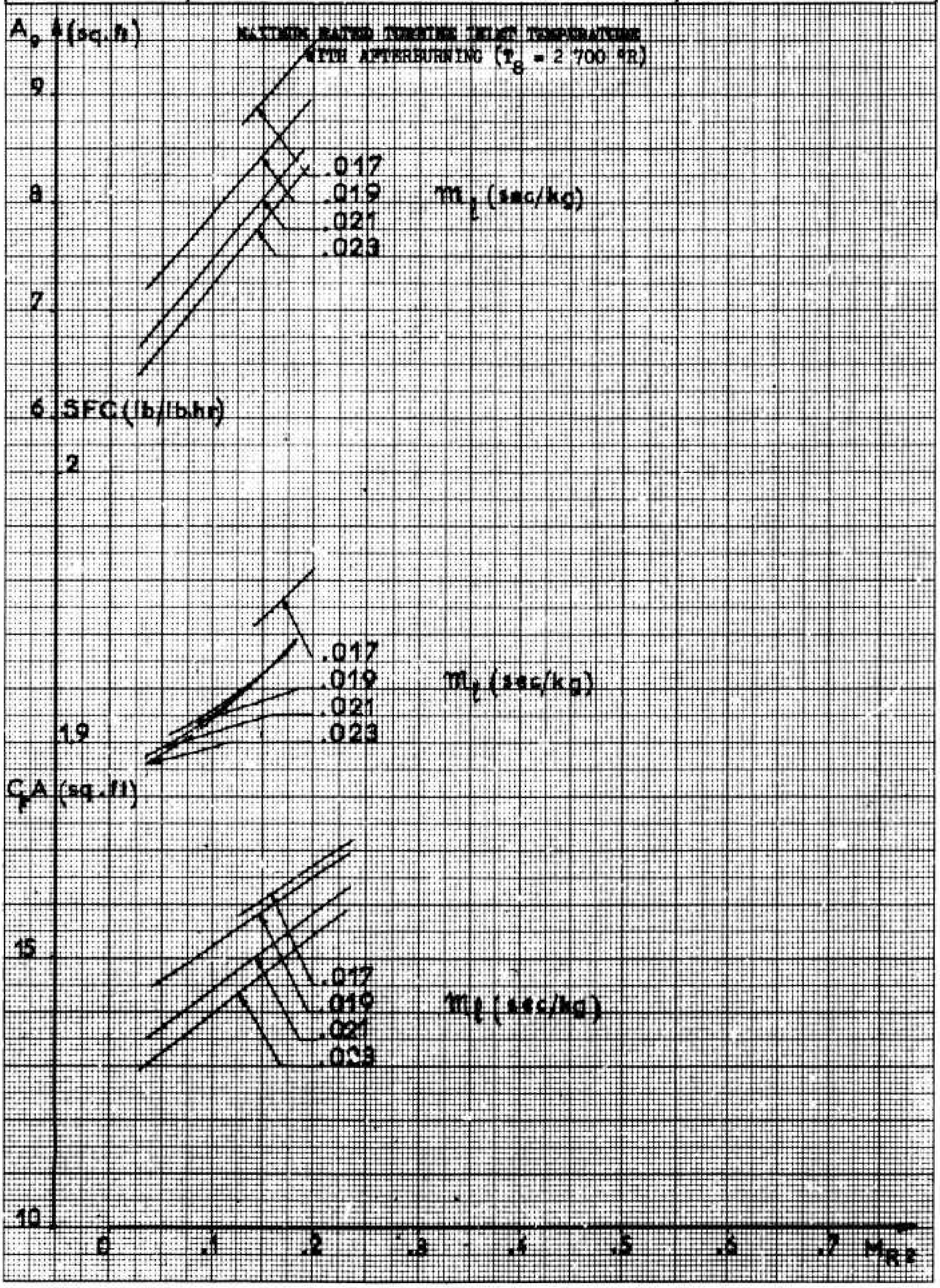
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 83



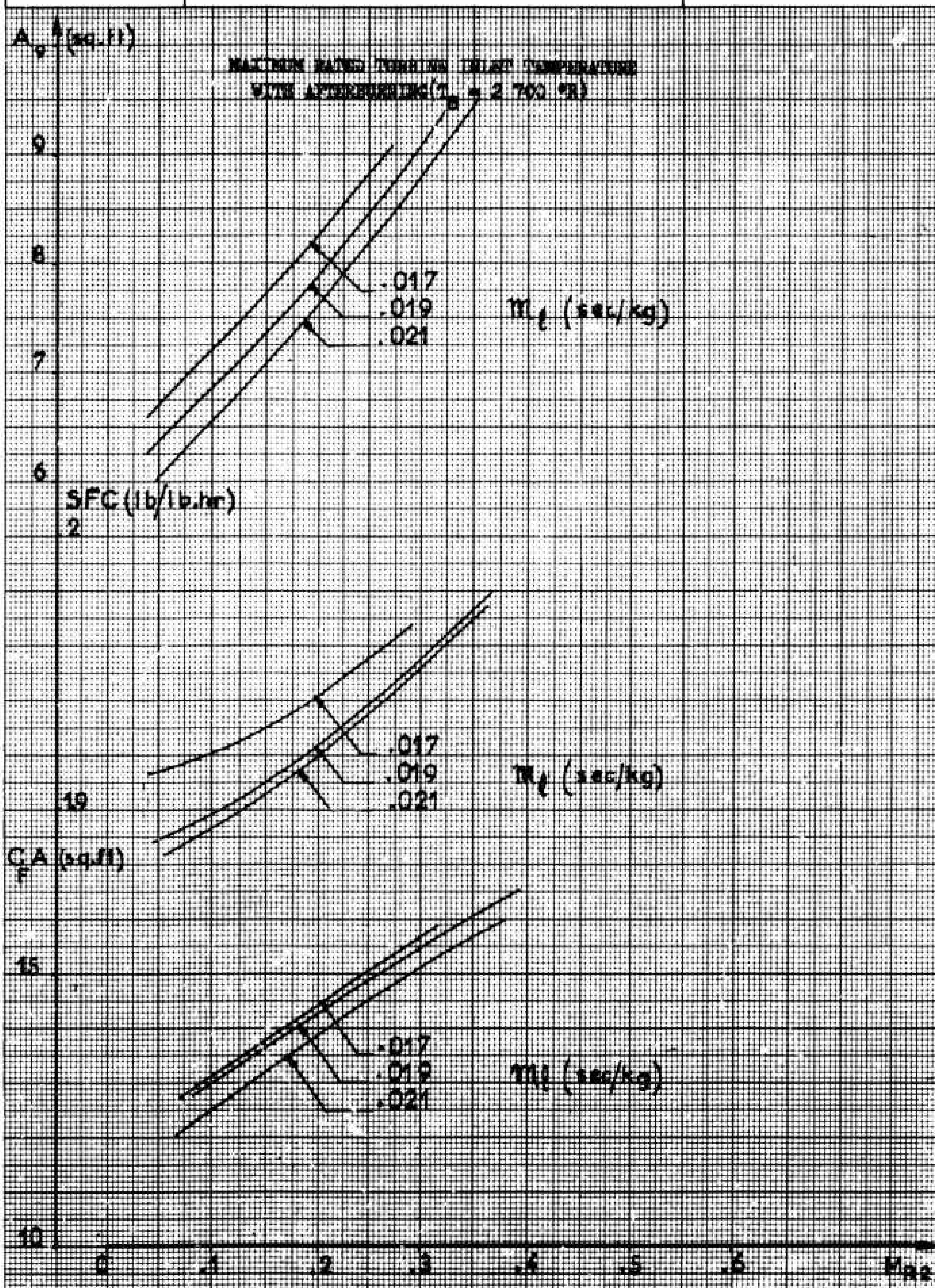
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 84



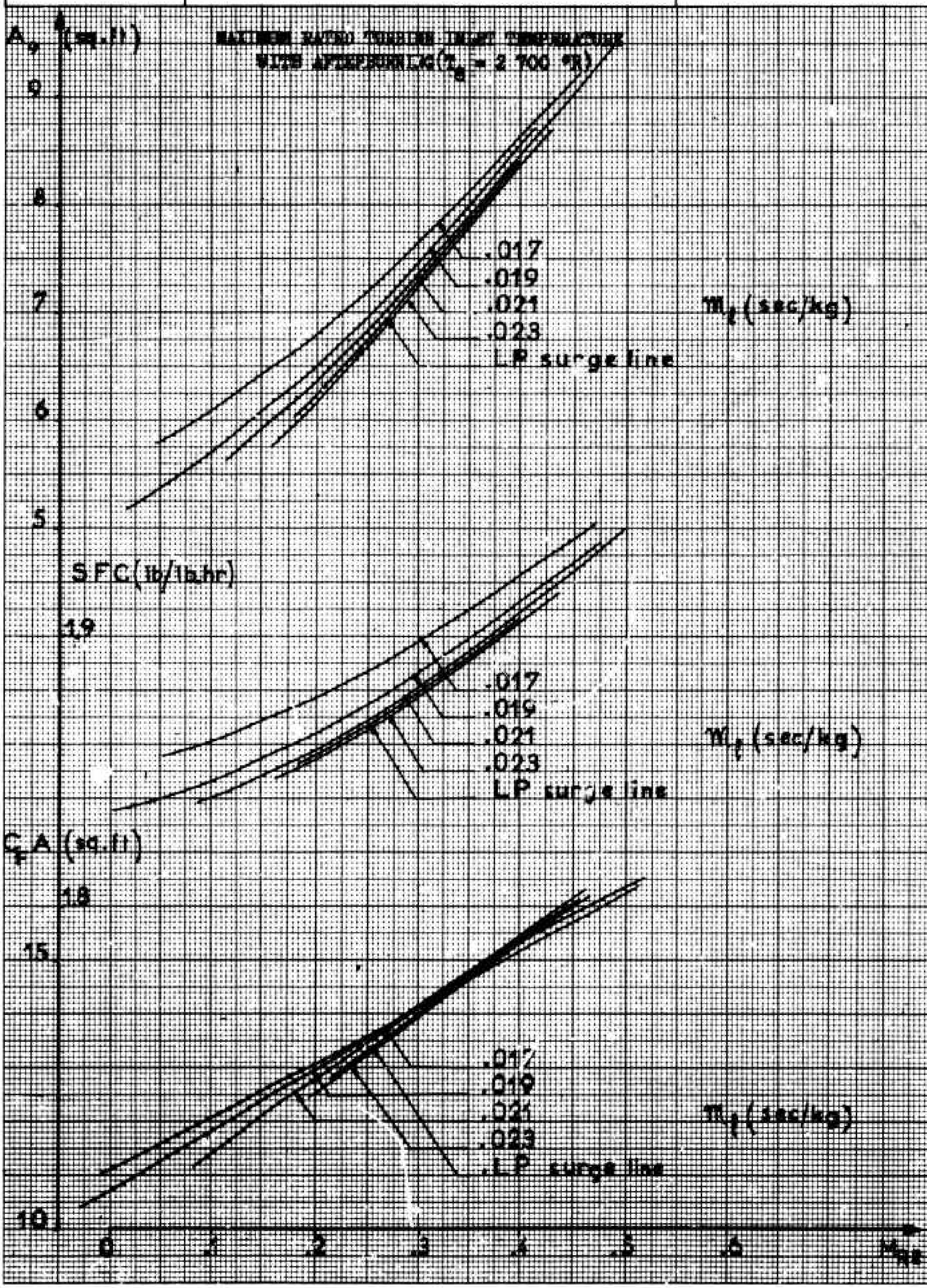
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 85



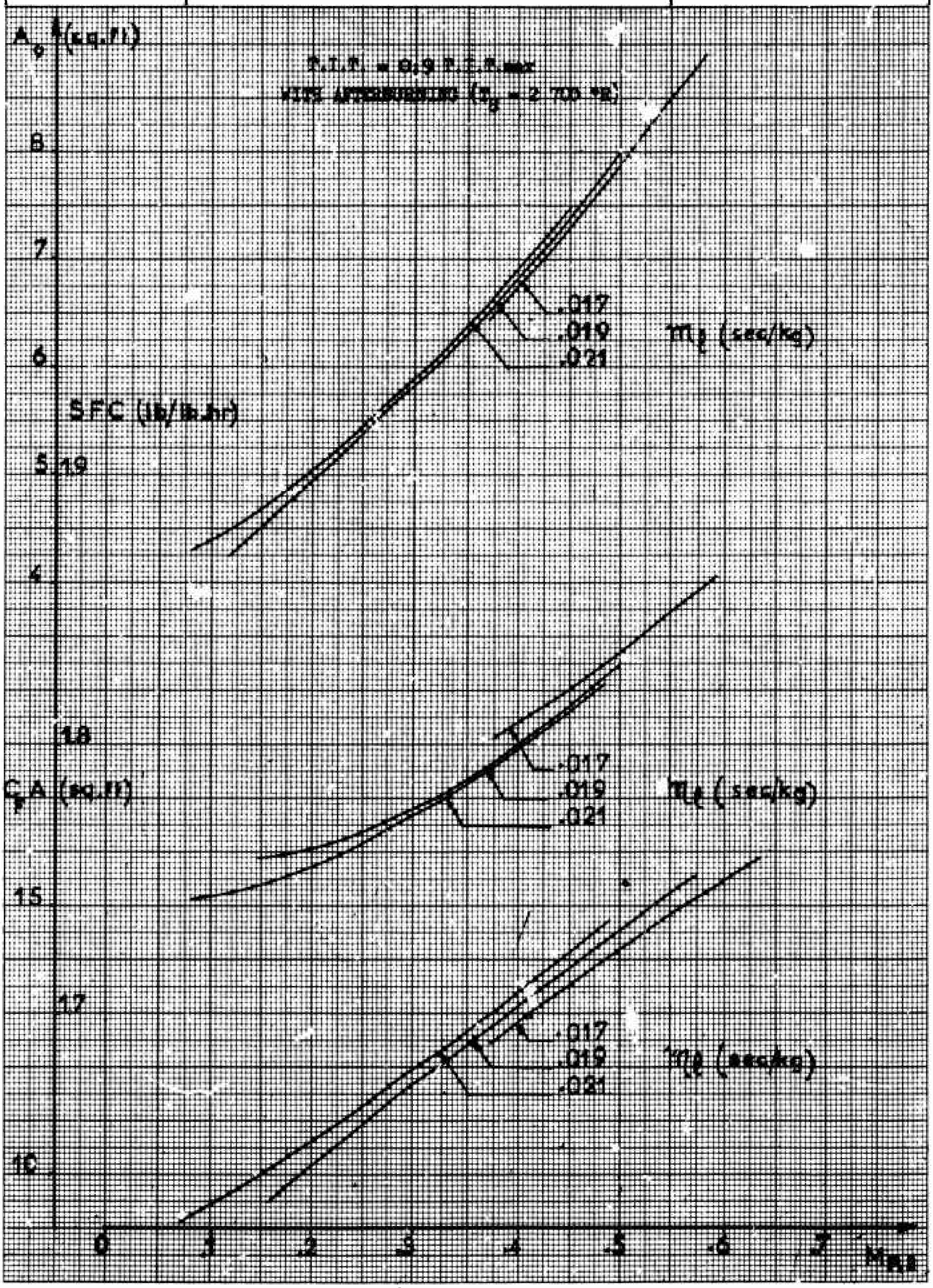
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2 Z = 36 000 ft	5152/NIOBE IV/34/2 Figure 86



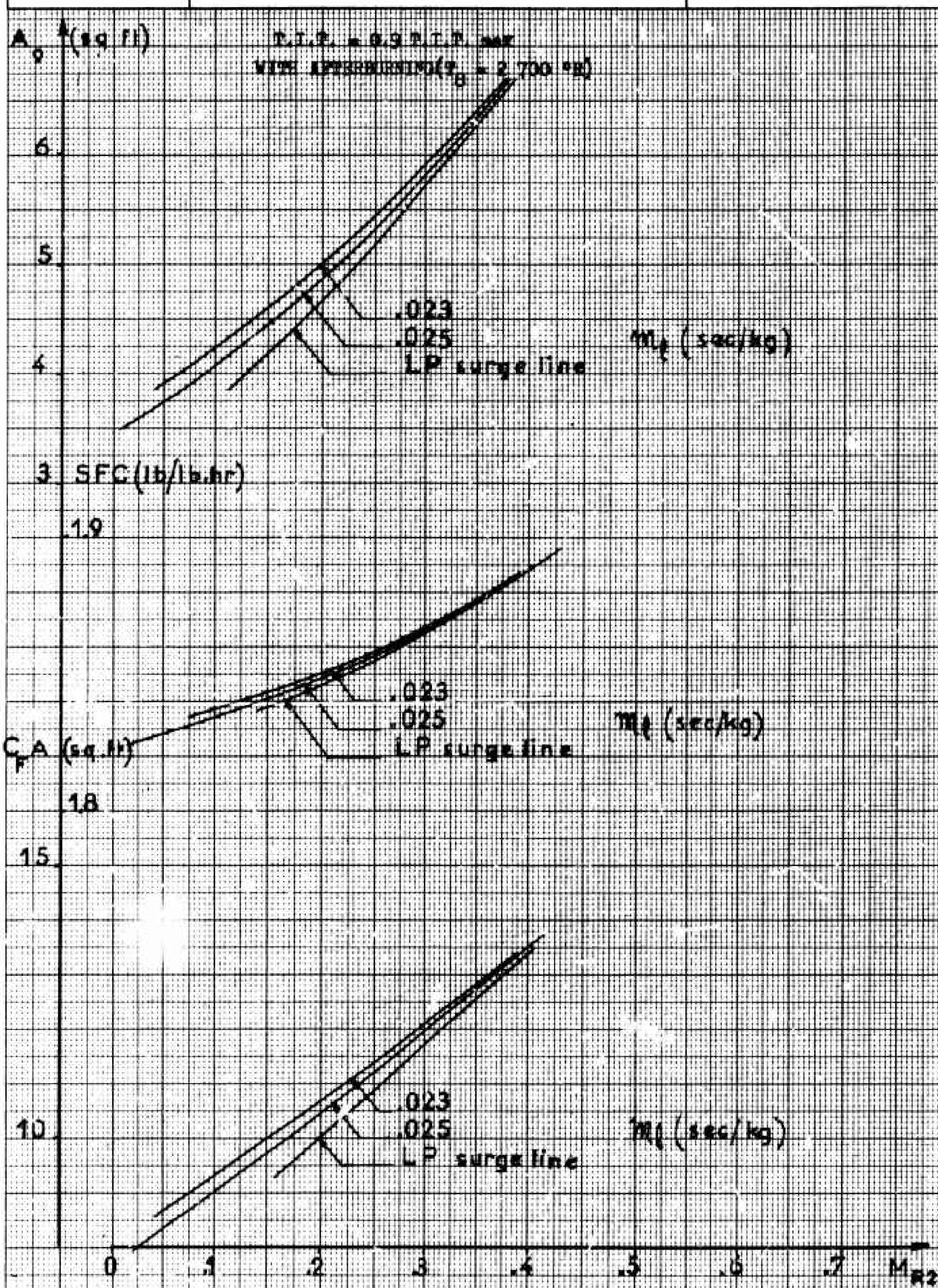
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.32 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 87



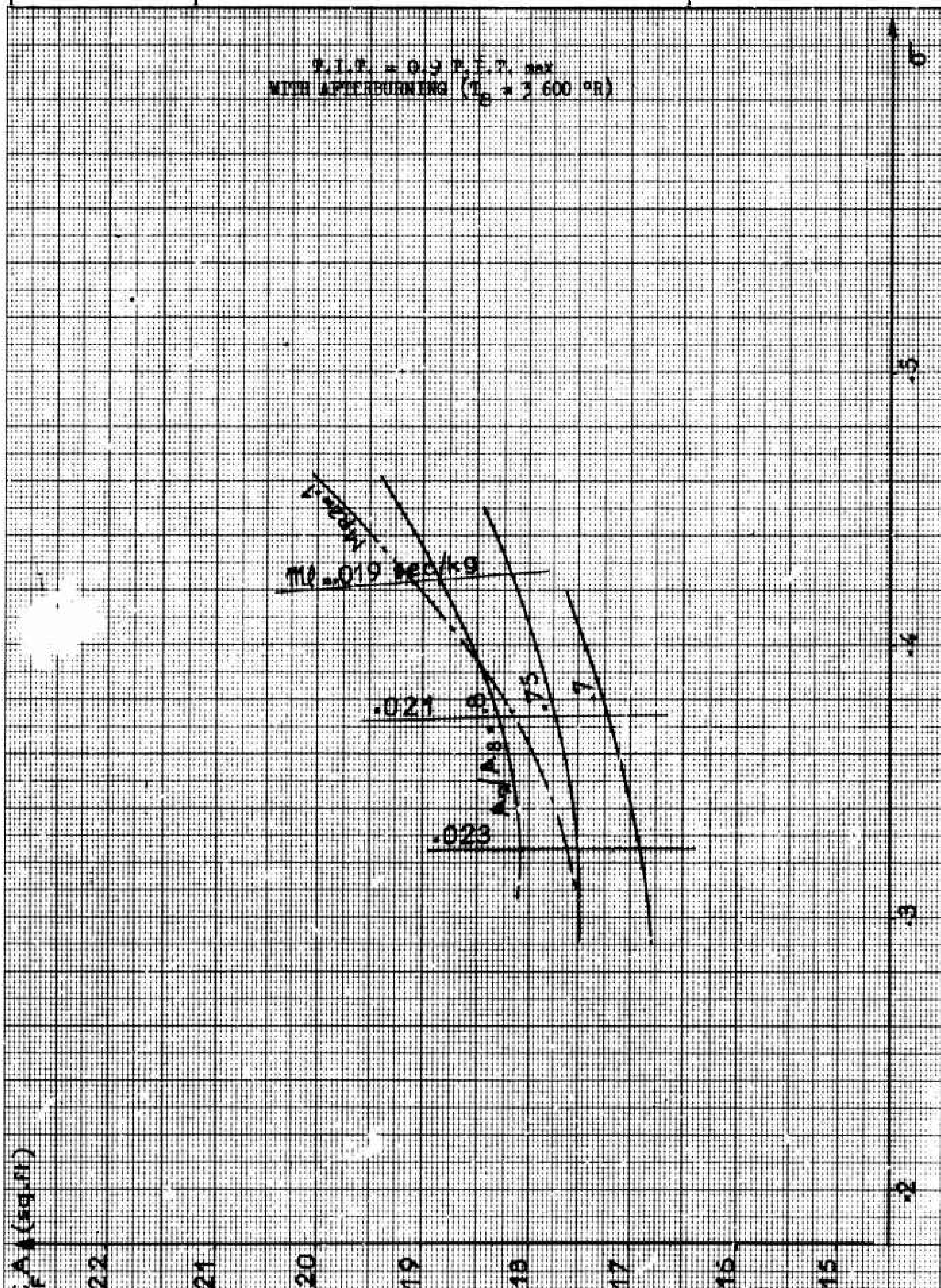
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 88



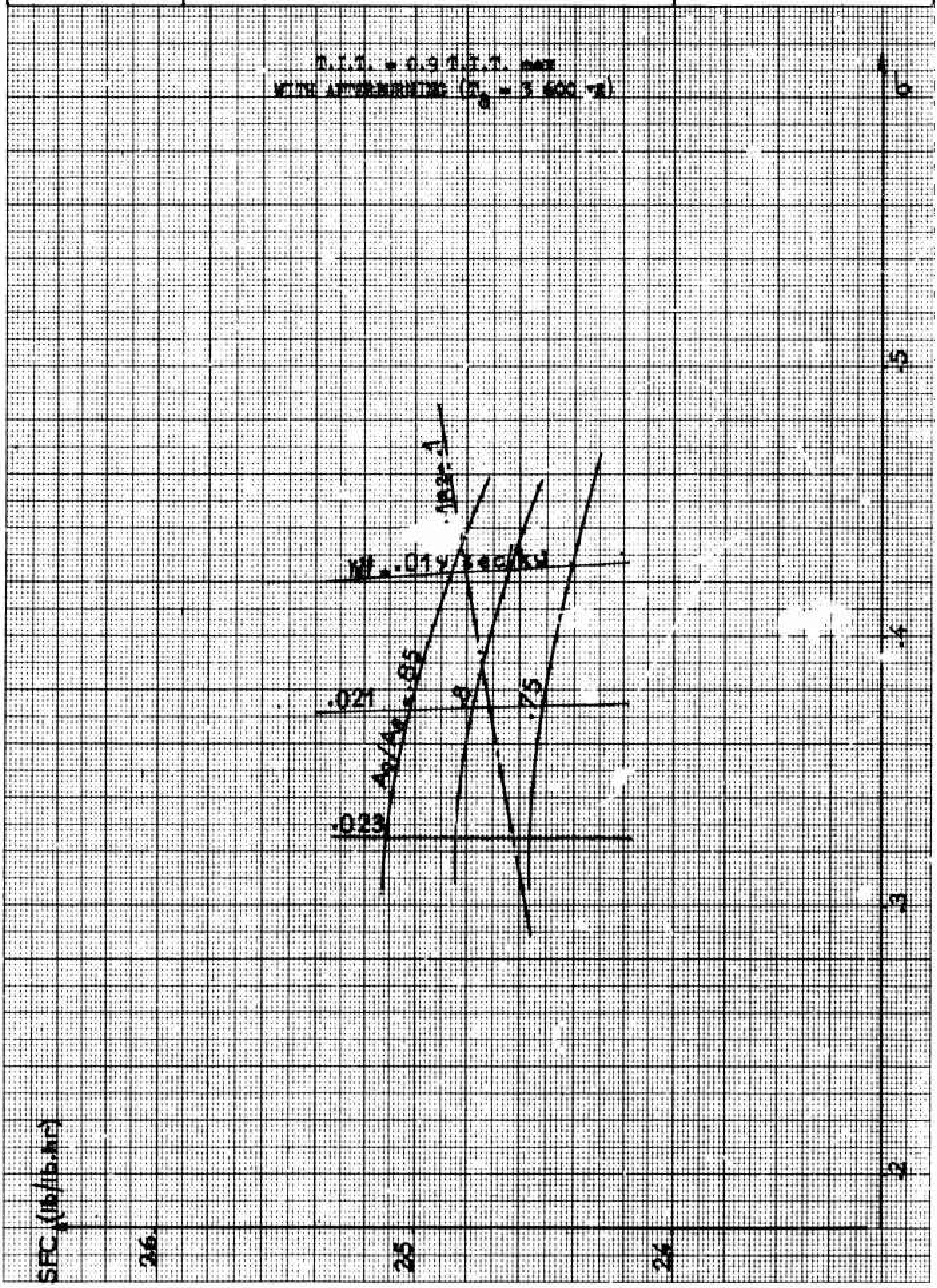
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 89



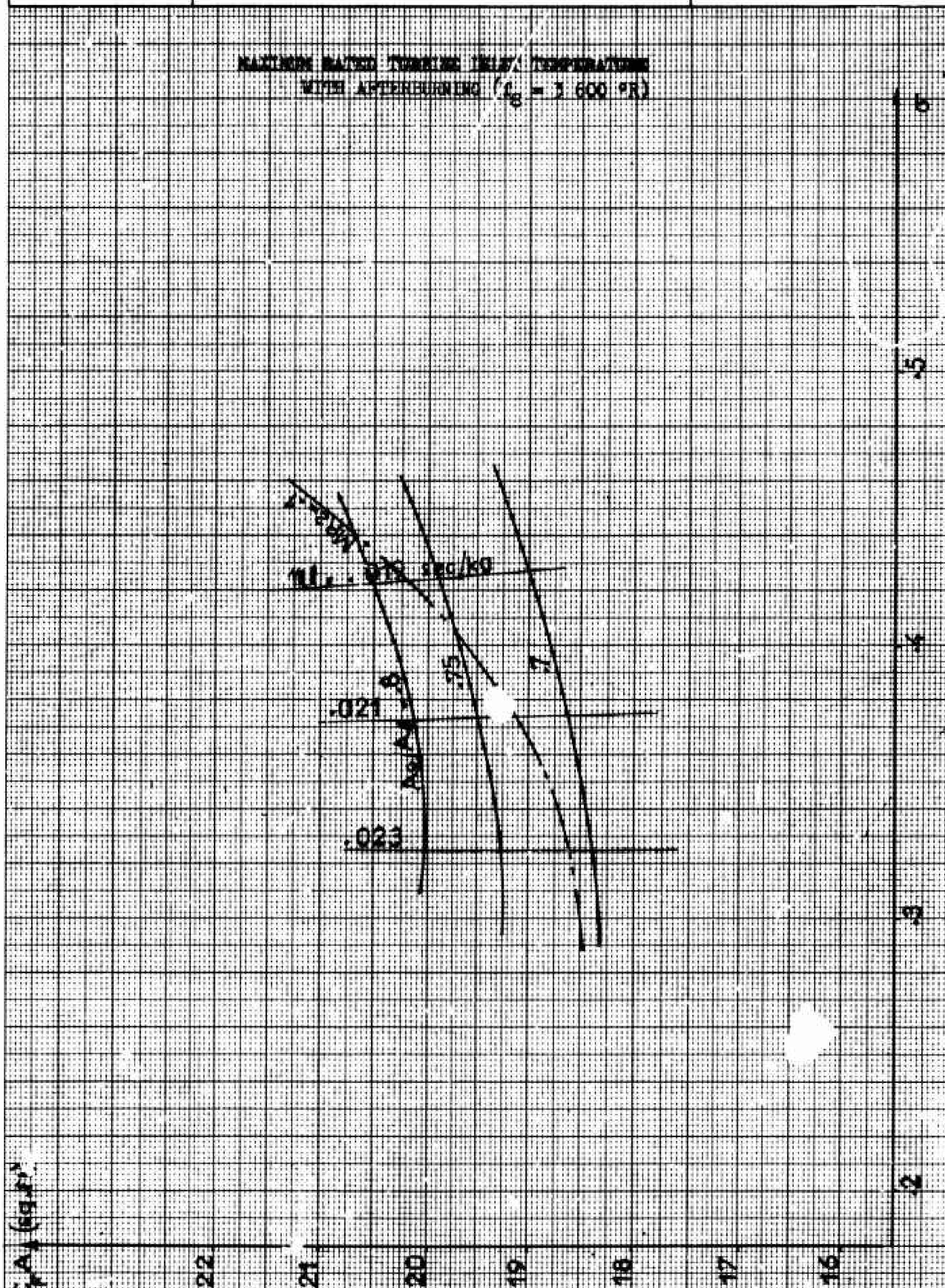
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 1.575 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 90



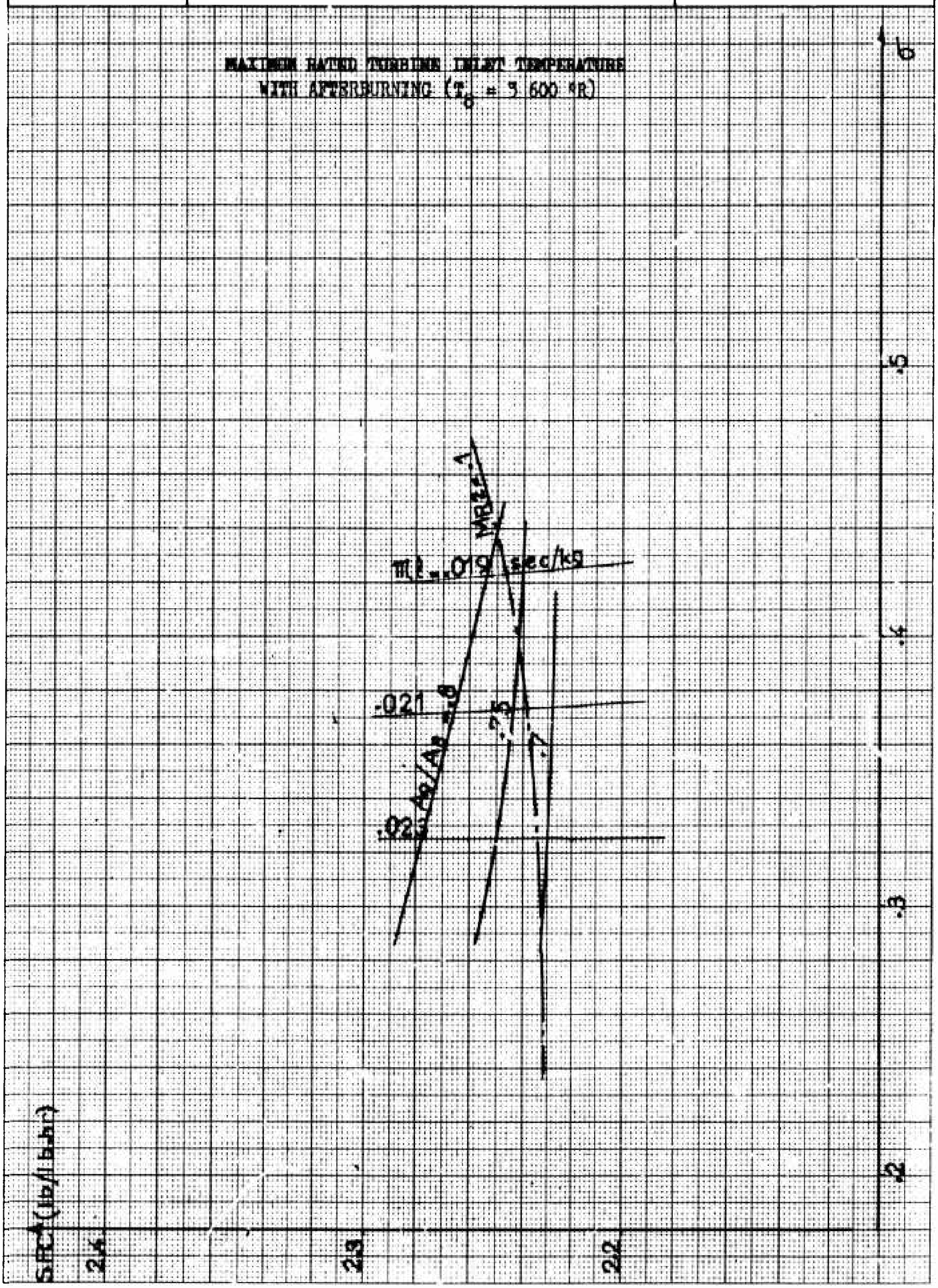
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 1.575 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 91



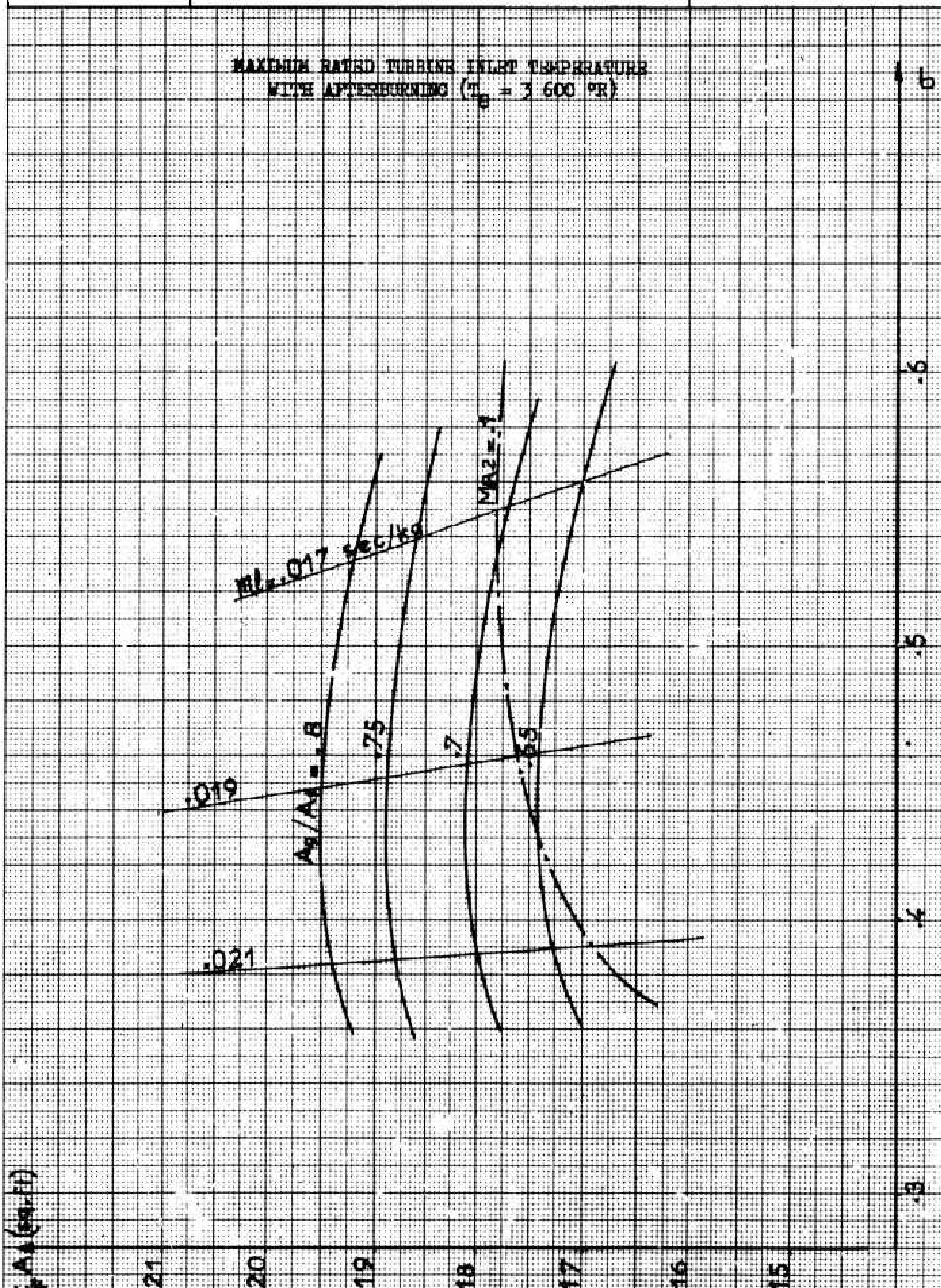
Nord-Aviation	TURBOFAN-RAMJET OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.82 Z = 36 000 ft	Figure 92



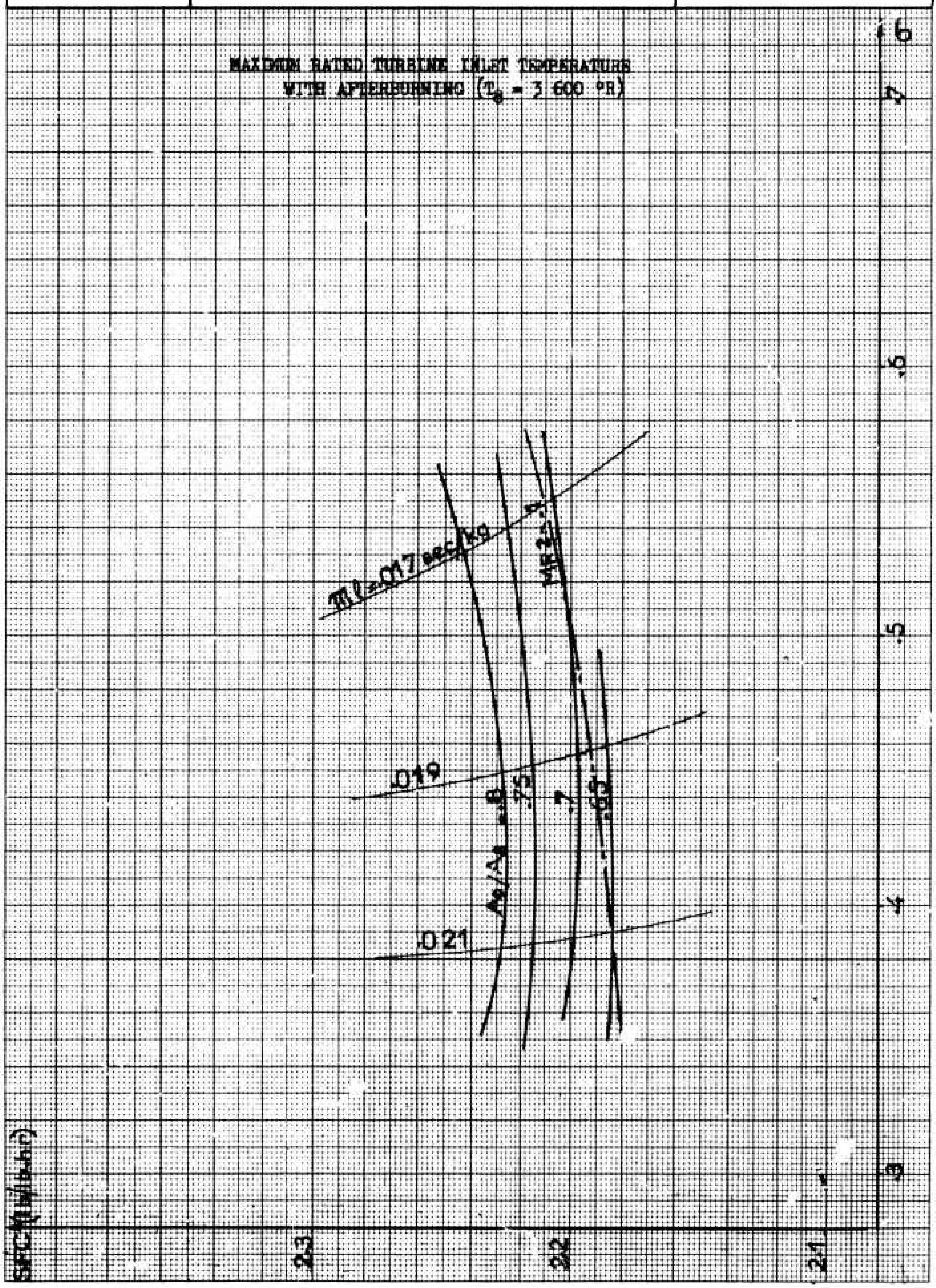
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 93



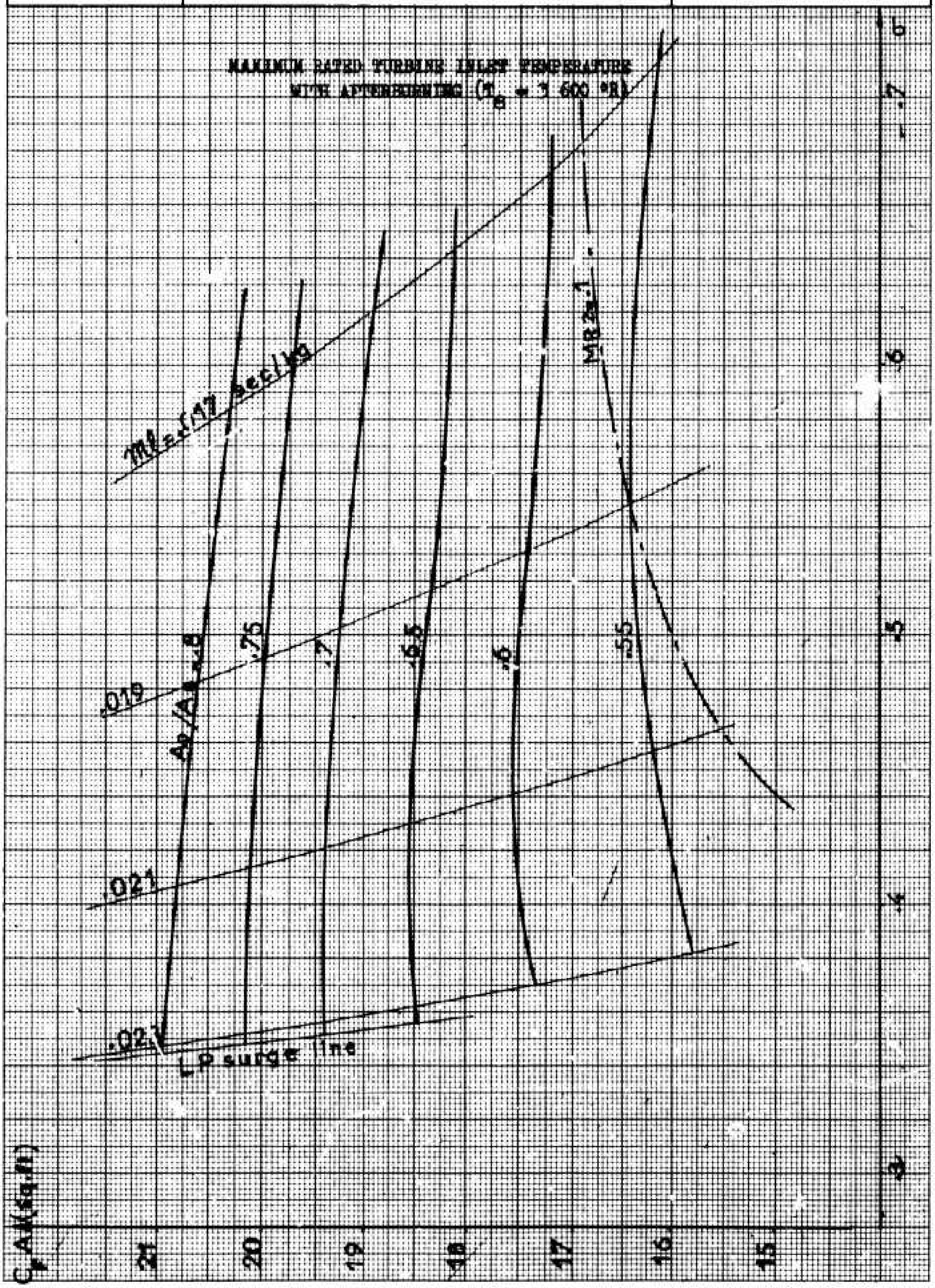
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 94



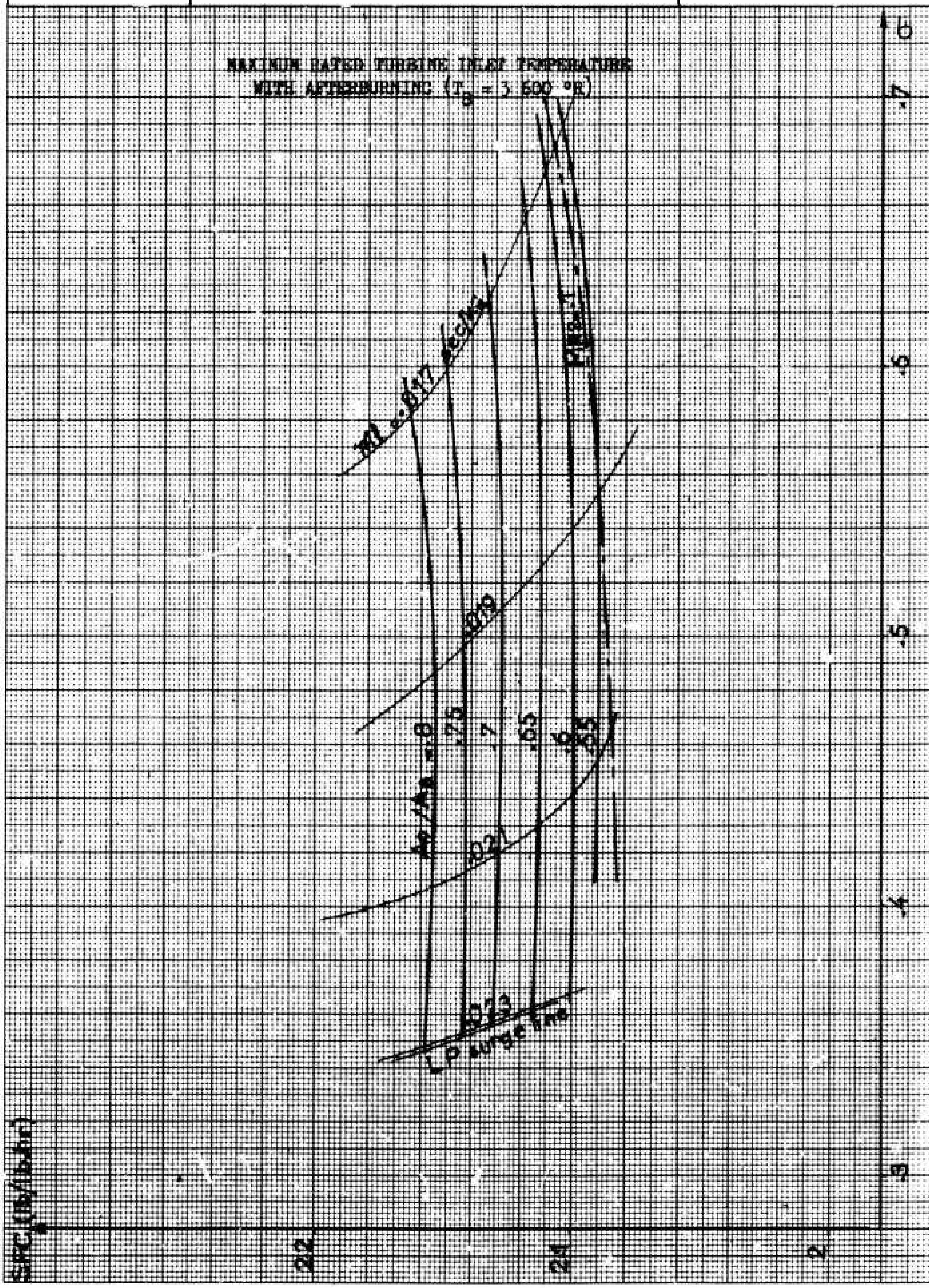
Nord-Aviation	TURBOFAN-RAMJET OPERATION	5152/NIOBE IV/34/Z
	Mo = 2. Z = 36 000 ft	Figure 95



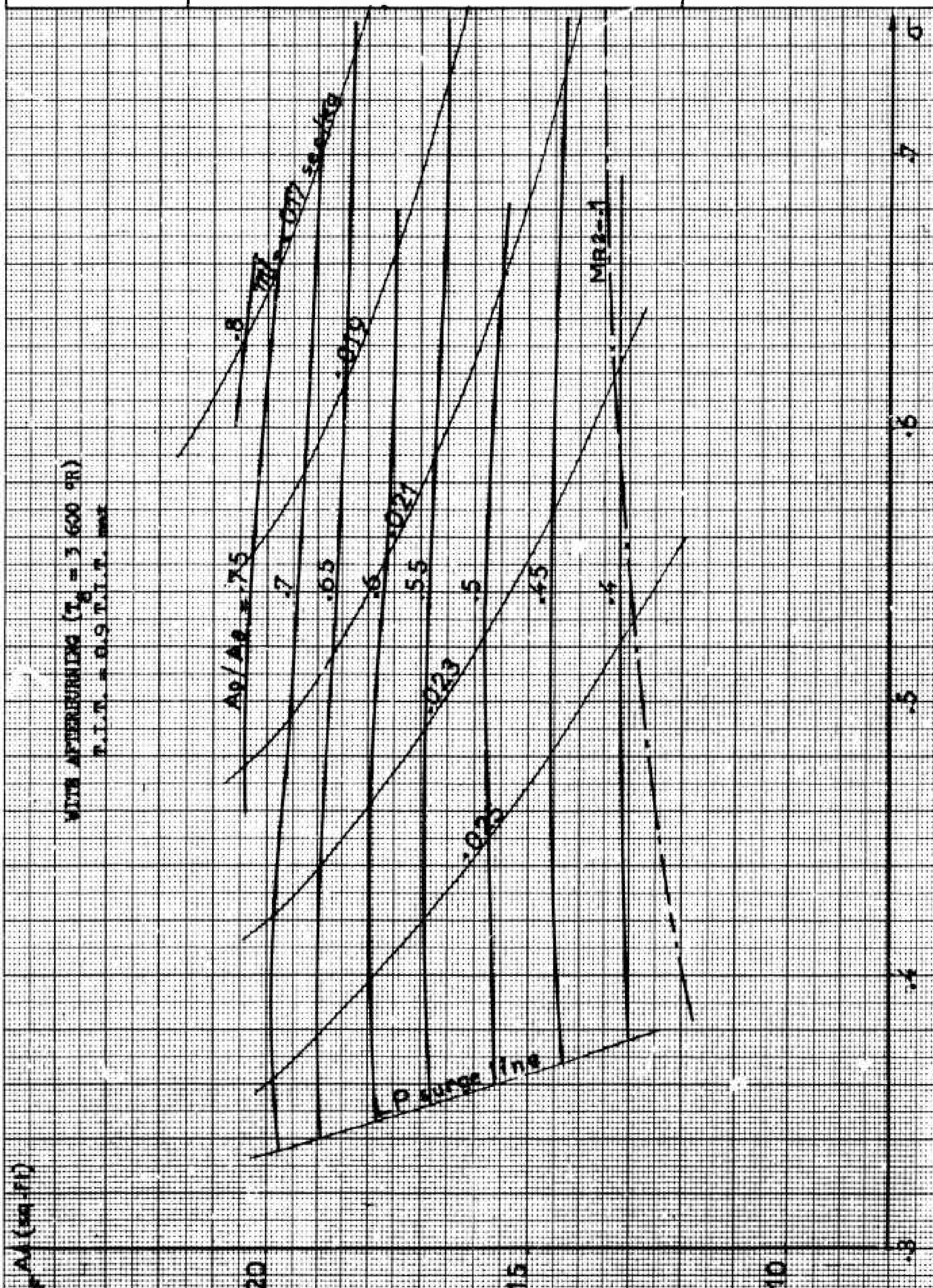
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.32 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 96



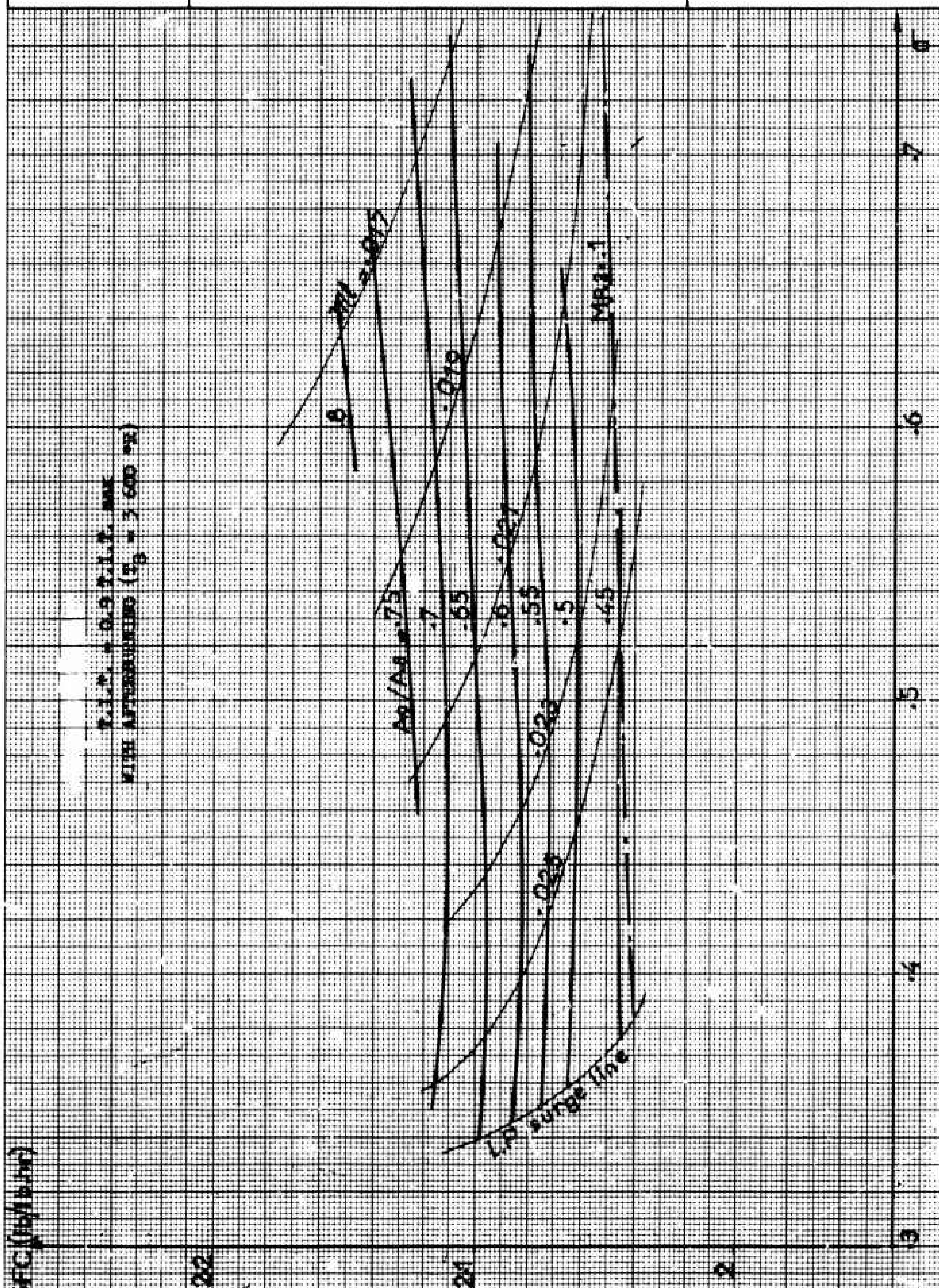
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.32 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 97



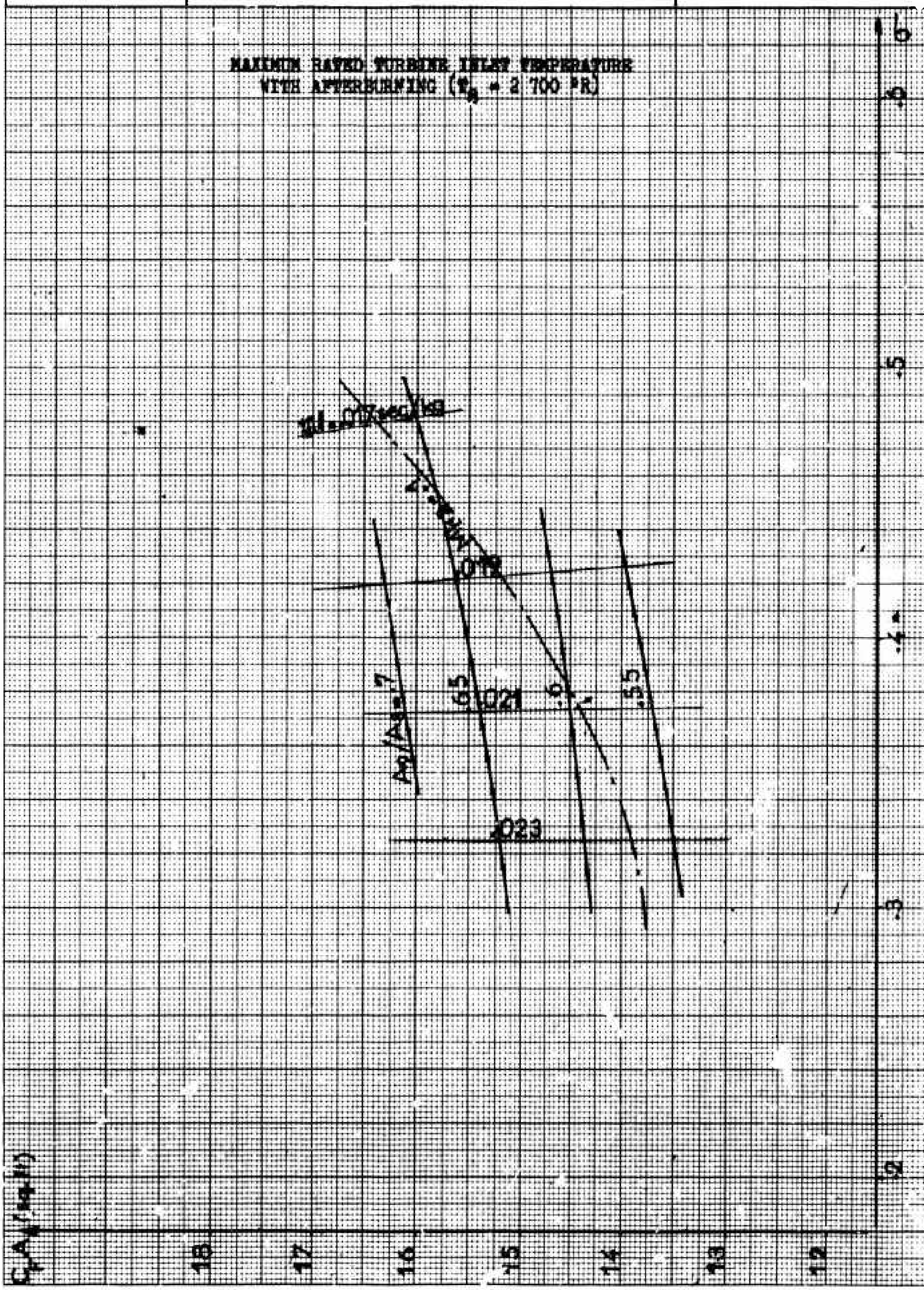
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 98



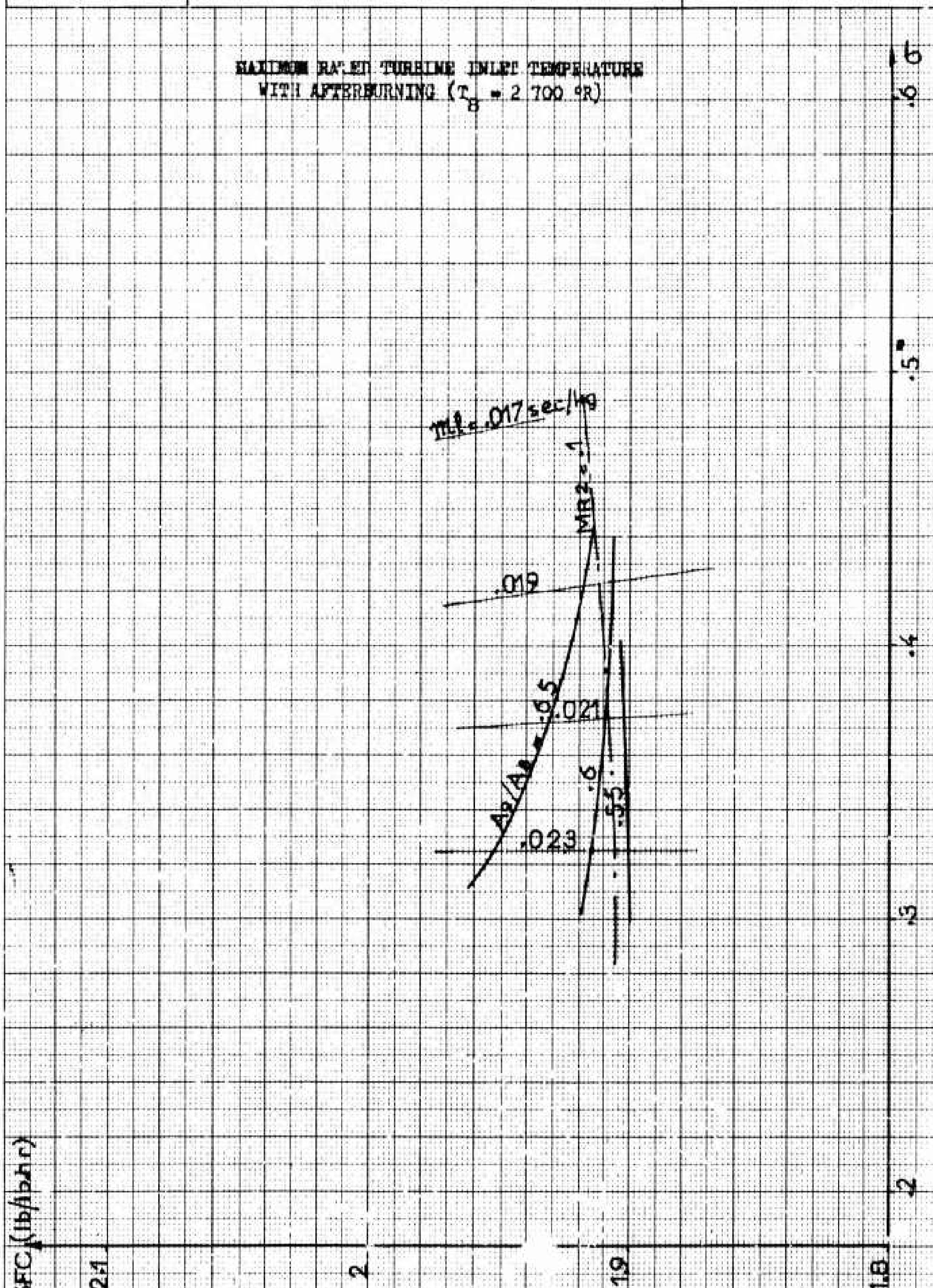
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 99



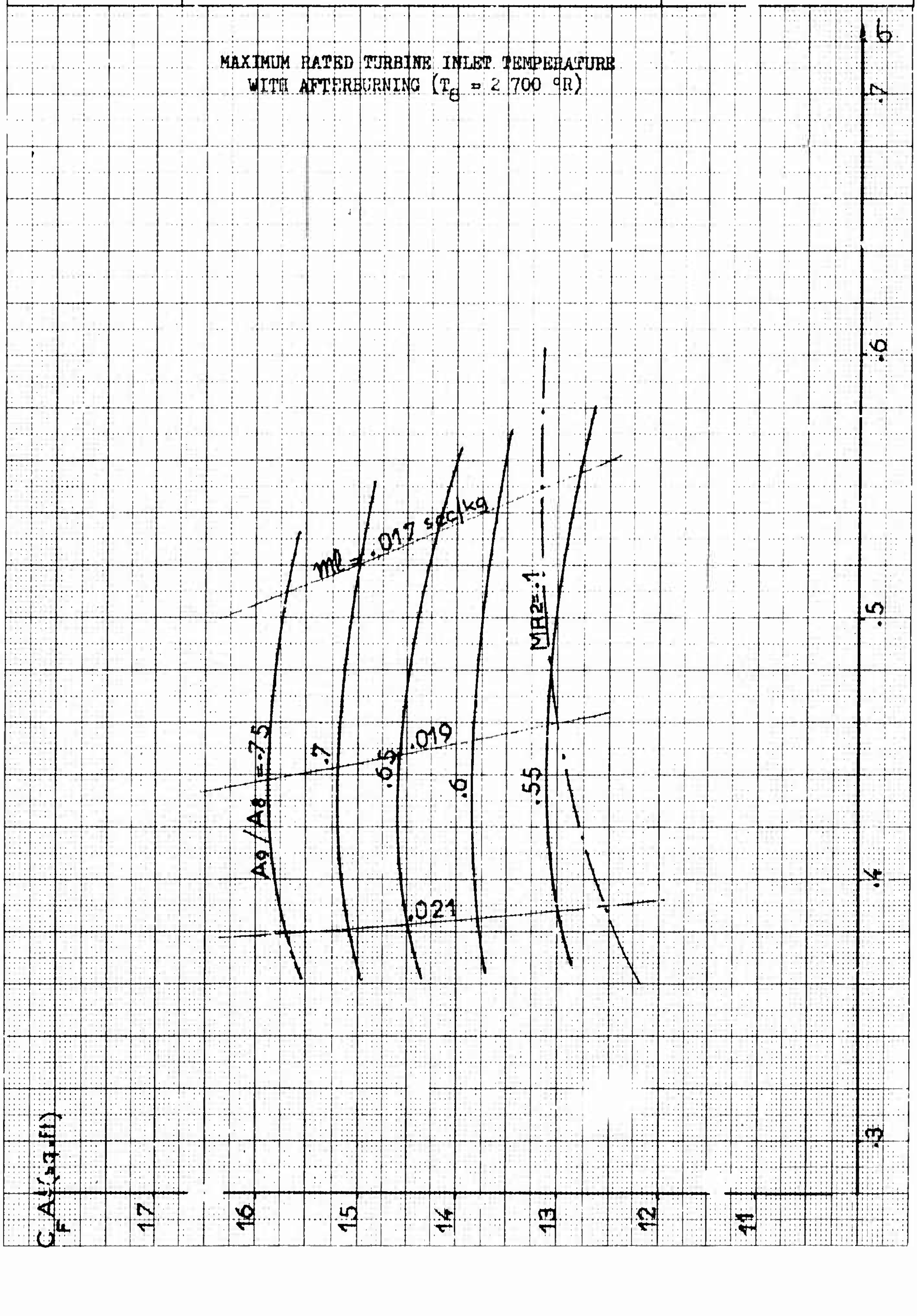
Nord-Aviation	TURBOFAN-RAMJET OPERATION	5152/NIOBE IV/34/Z
	Mo = 1.82 Z = 36 000 ft	Figure 100



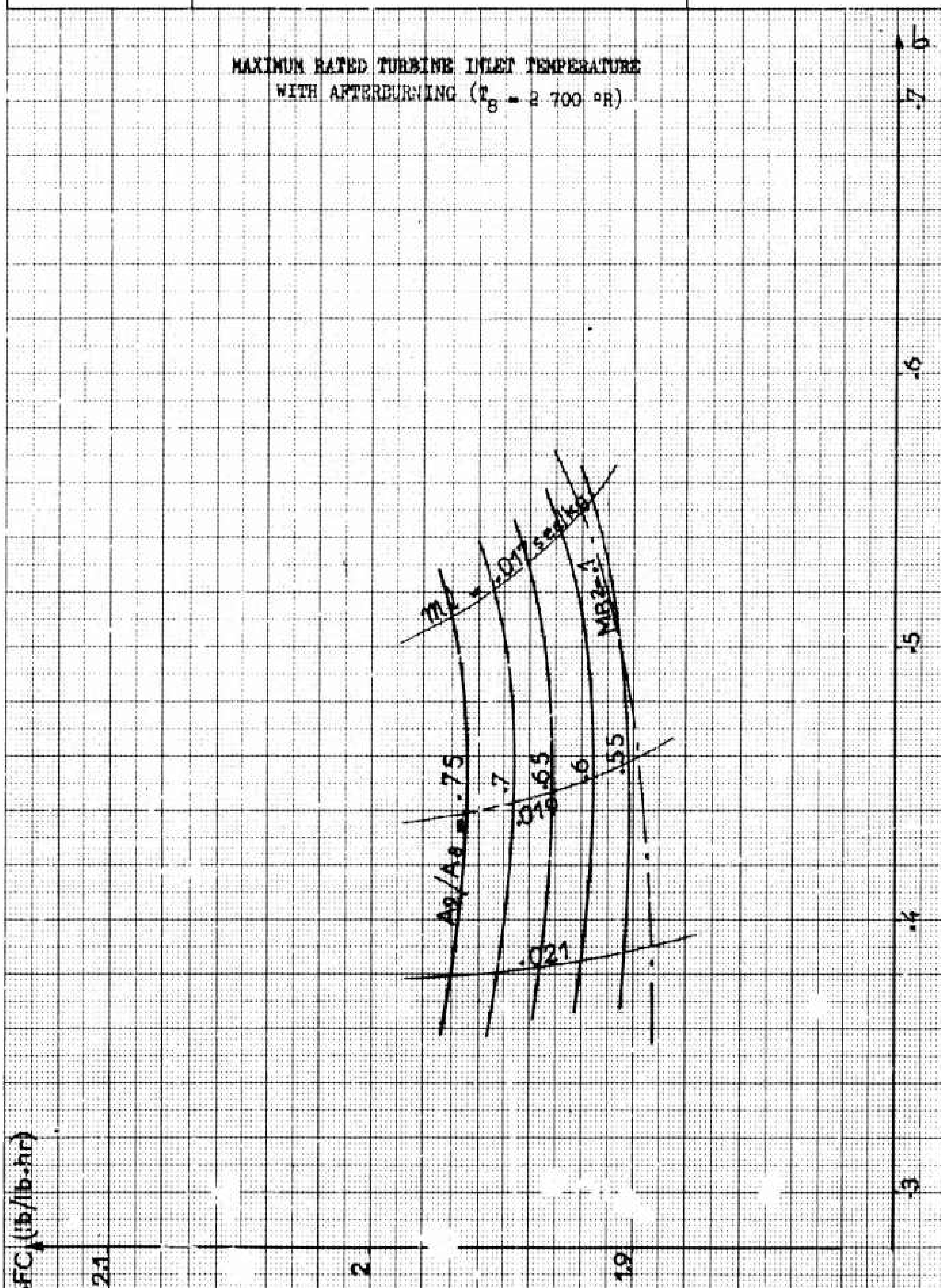
Nord Aviation	TURBOFAN-RAMJET OPERATION Mo = 1.82 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 101



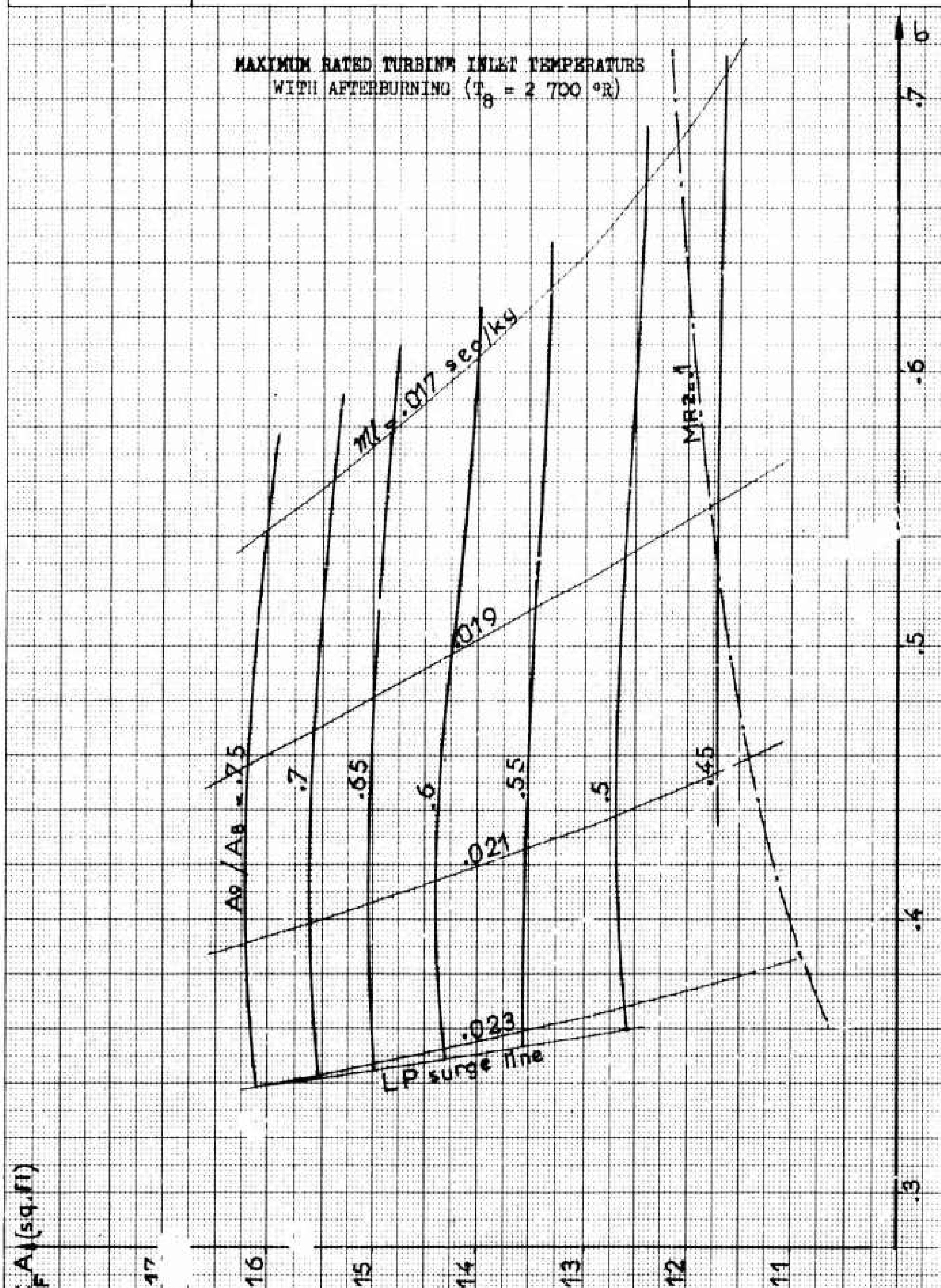
Nord-Aviation	TURBOFAN RAMJET OPERATION Mo = 2 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 102



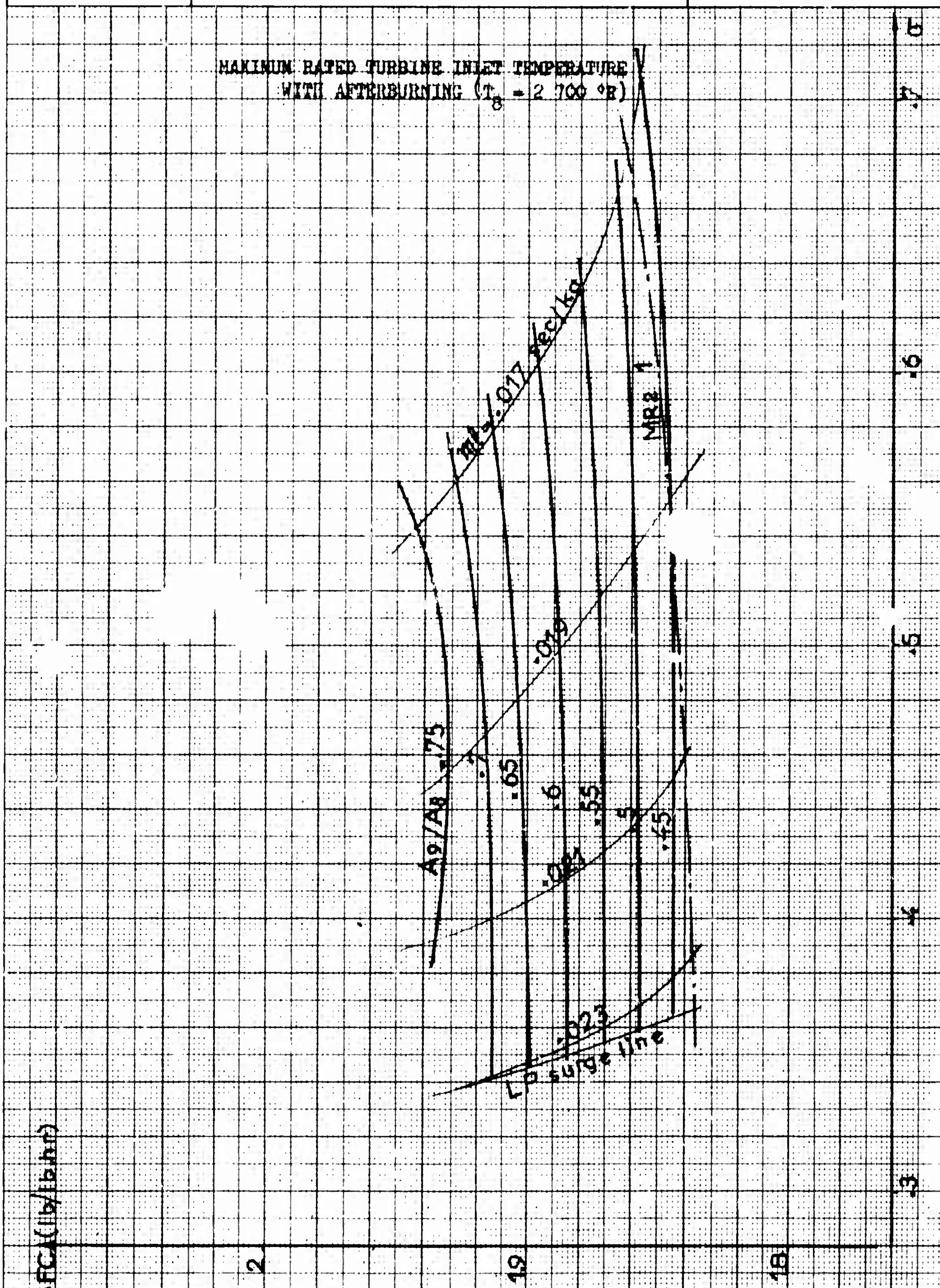
Nord Aviation	TURBOFAN-RAMJET OPERATION Mo = 2 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 103



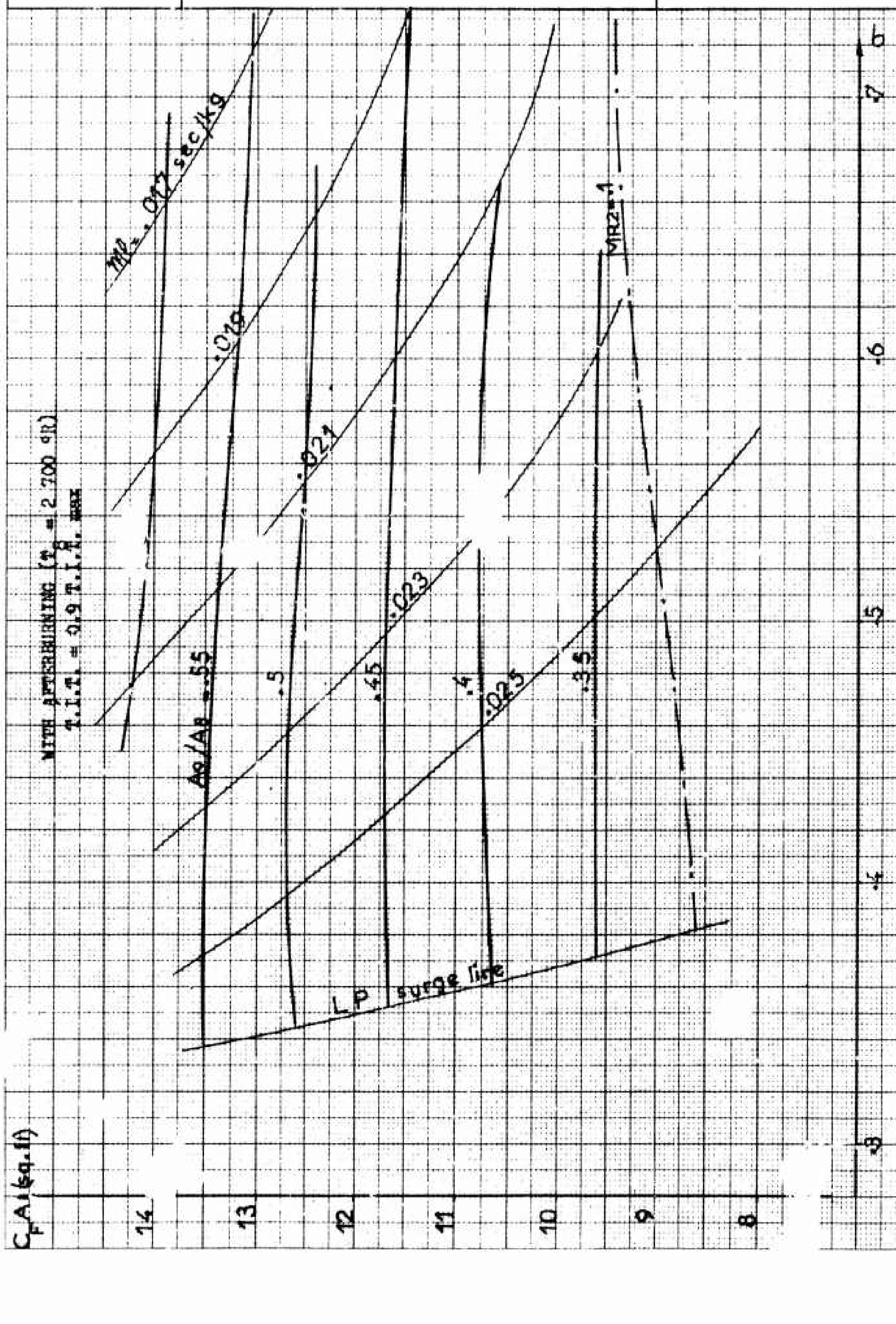
Nord Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.32 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 104



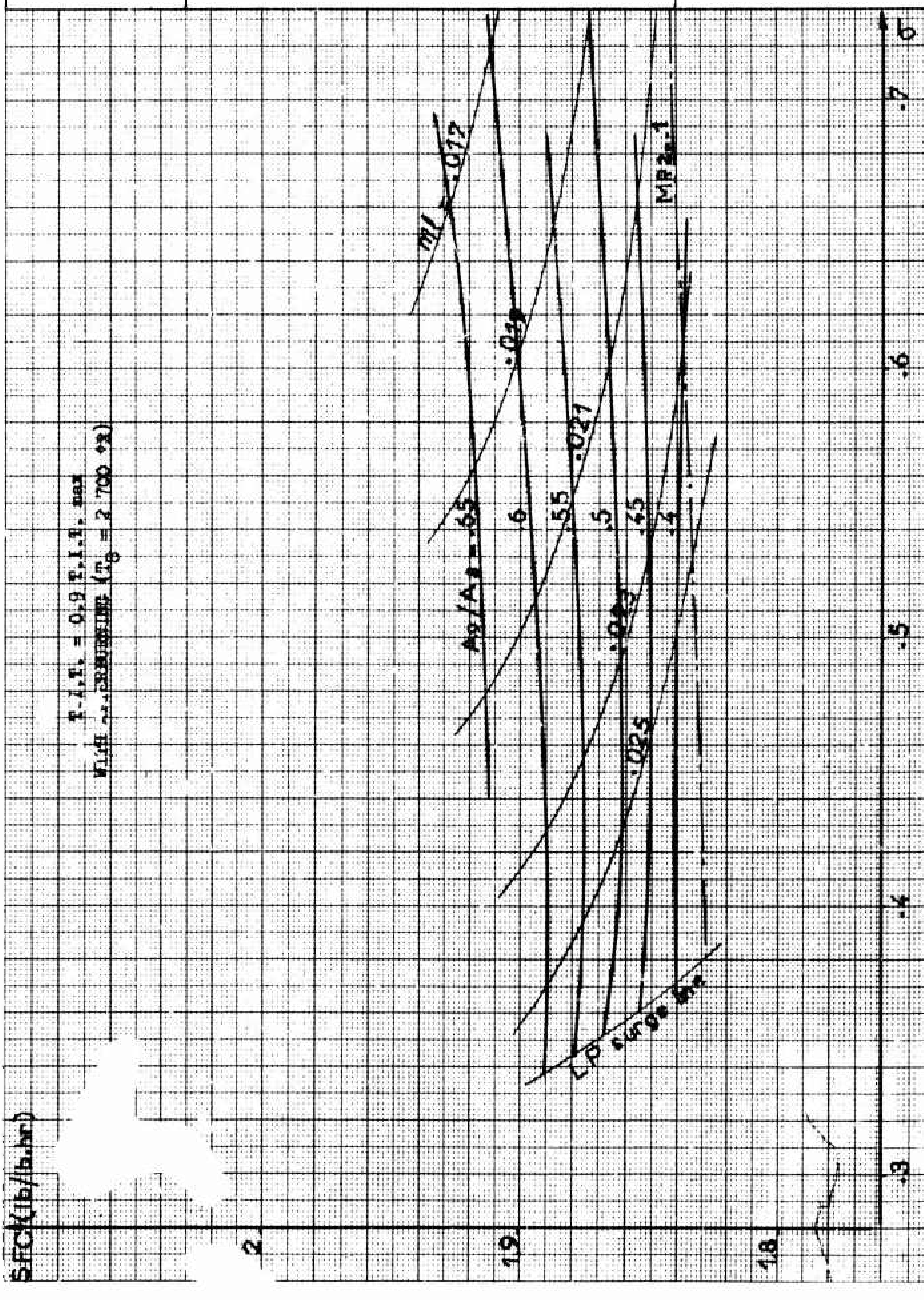
Nord-Aviation	TURBOFAN–RAMJET OPERATION Mo = 2.32 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 105



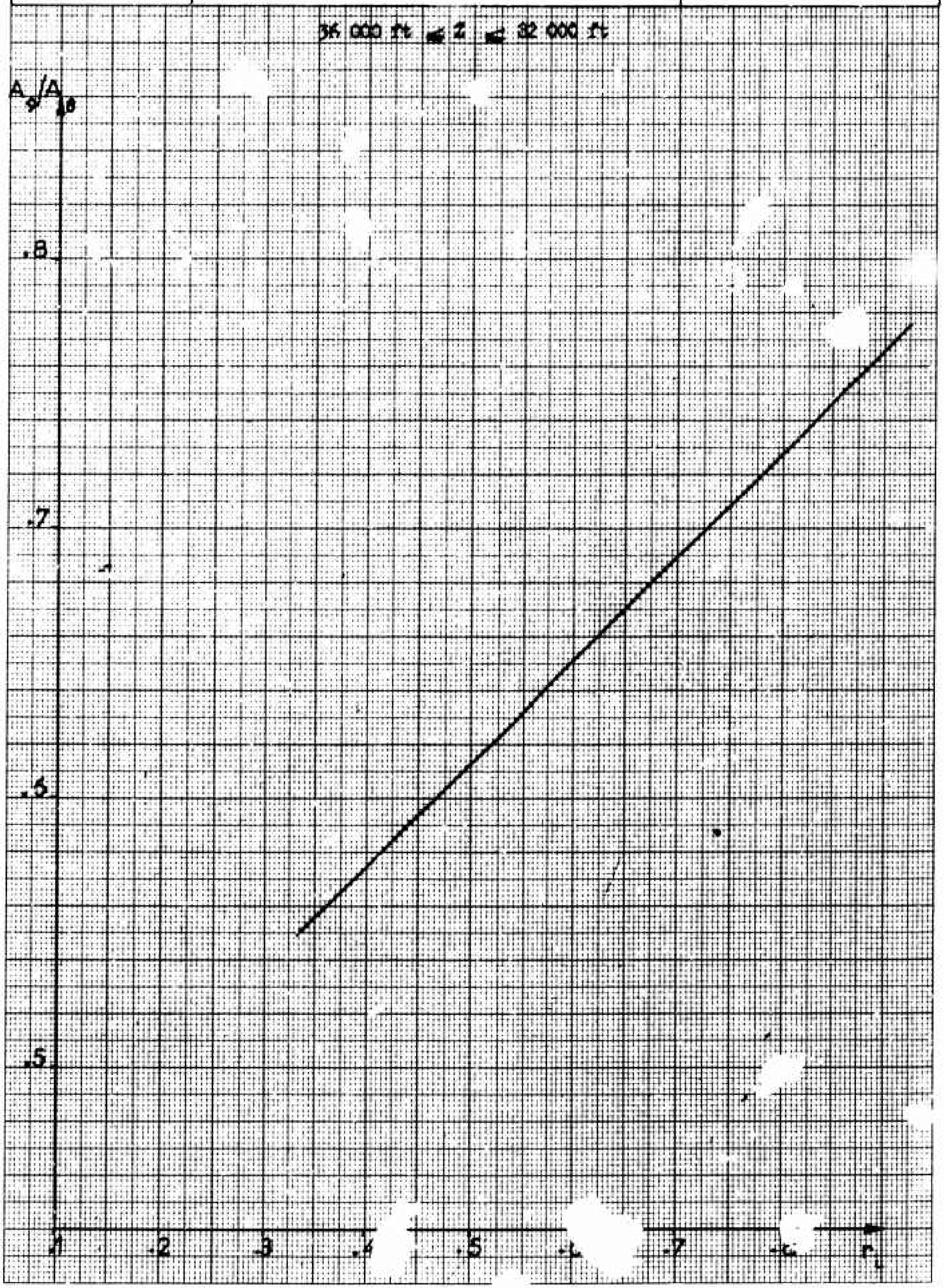
Nord Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 106



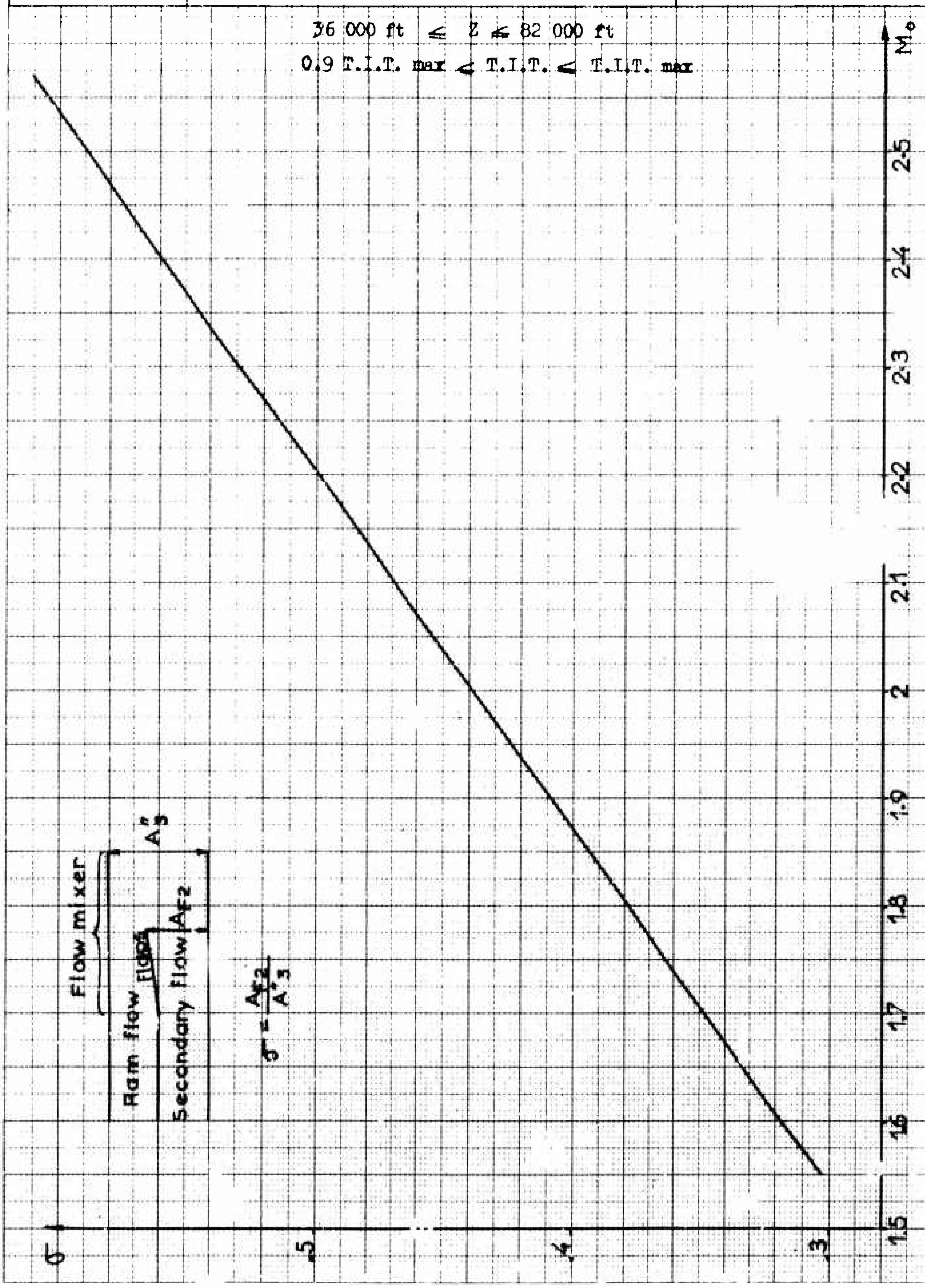
Nord-Aviation	TURBOFAN-RAMJET OPERATION Mo = 2.536 Z = 36 000 ft	5152/NIOBE IV/34/Z Figure 107



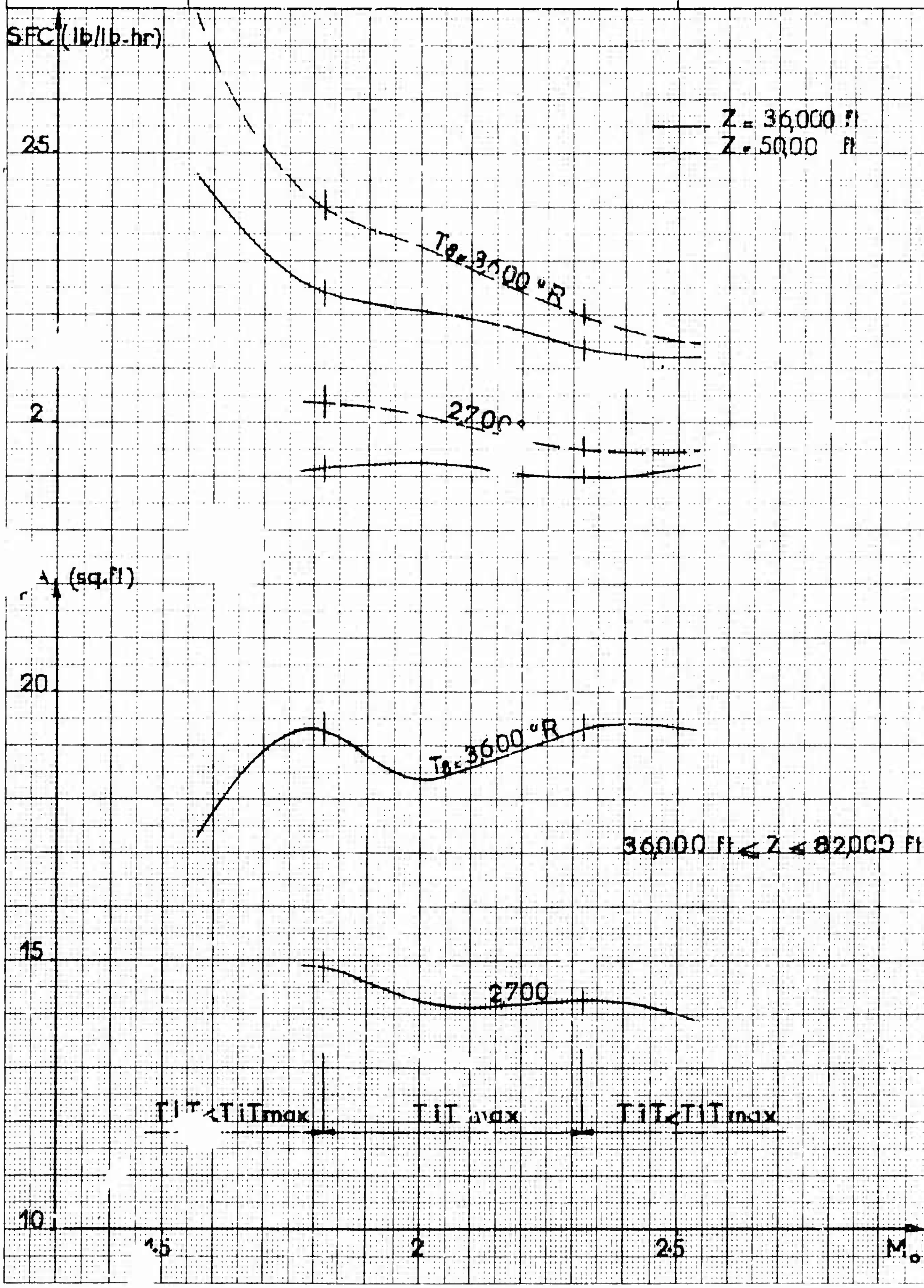
Nord-Aviation	TURBOFAN-RAMJET OPERATION Nozzle throat and fuel control	5152/NIOBE IV/34/Z Figure 108



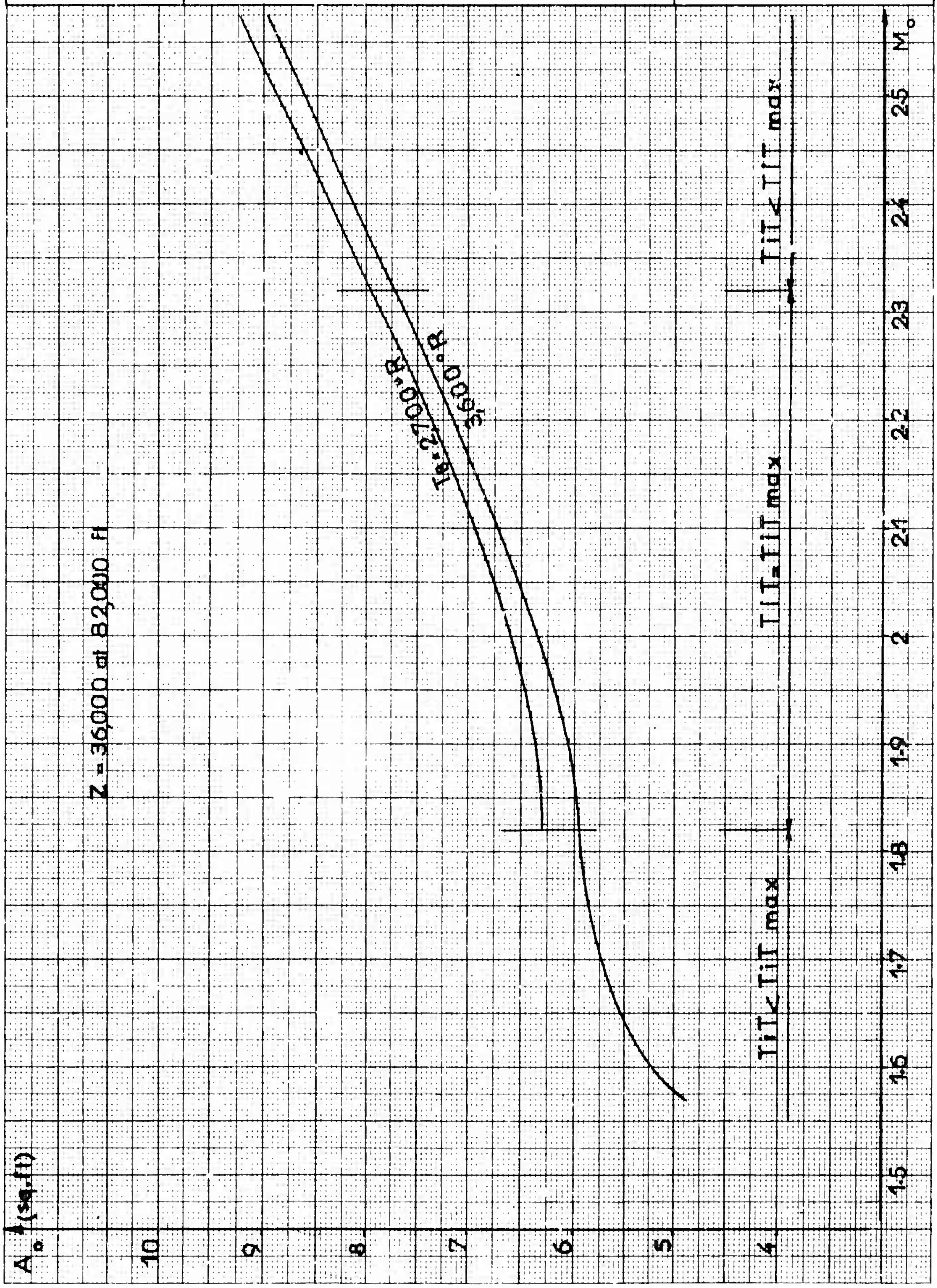
Nord Aviation	TURBOFAN-RAMJET OPERATION Control of flow mixer flaps position	5152/NIOBE IV/34/2 Figure 109



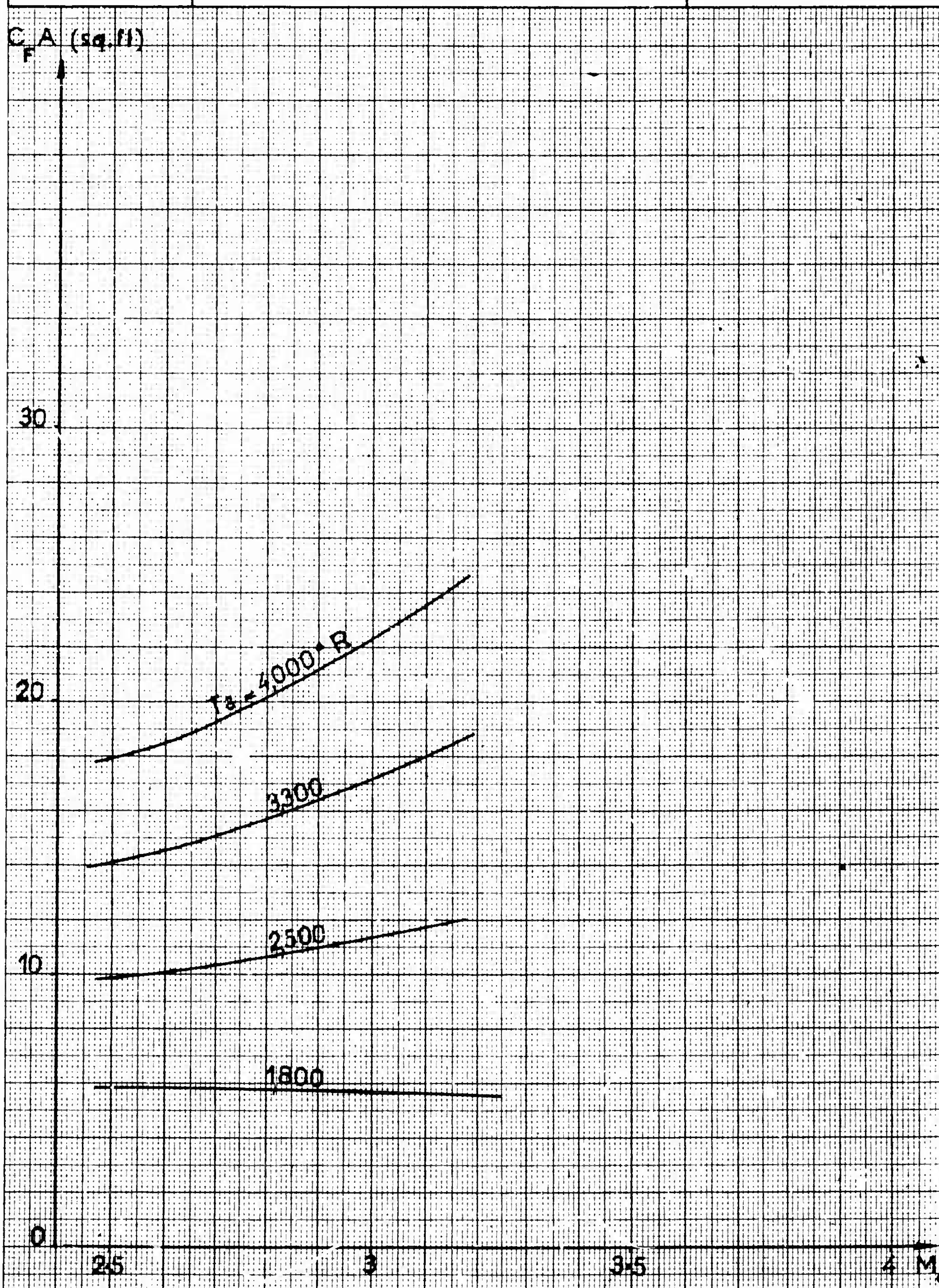
Nord-Aviation	TURBOFAN-RAMJET OPERATION Thrust and specific fuel consumption	5152/NIOBE IV/34/Z Figure 110



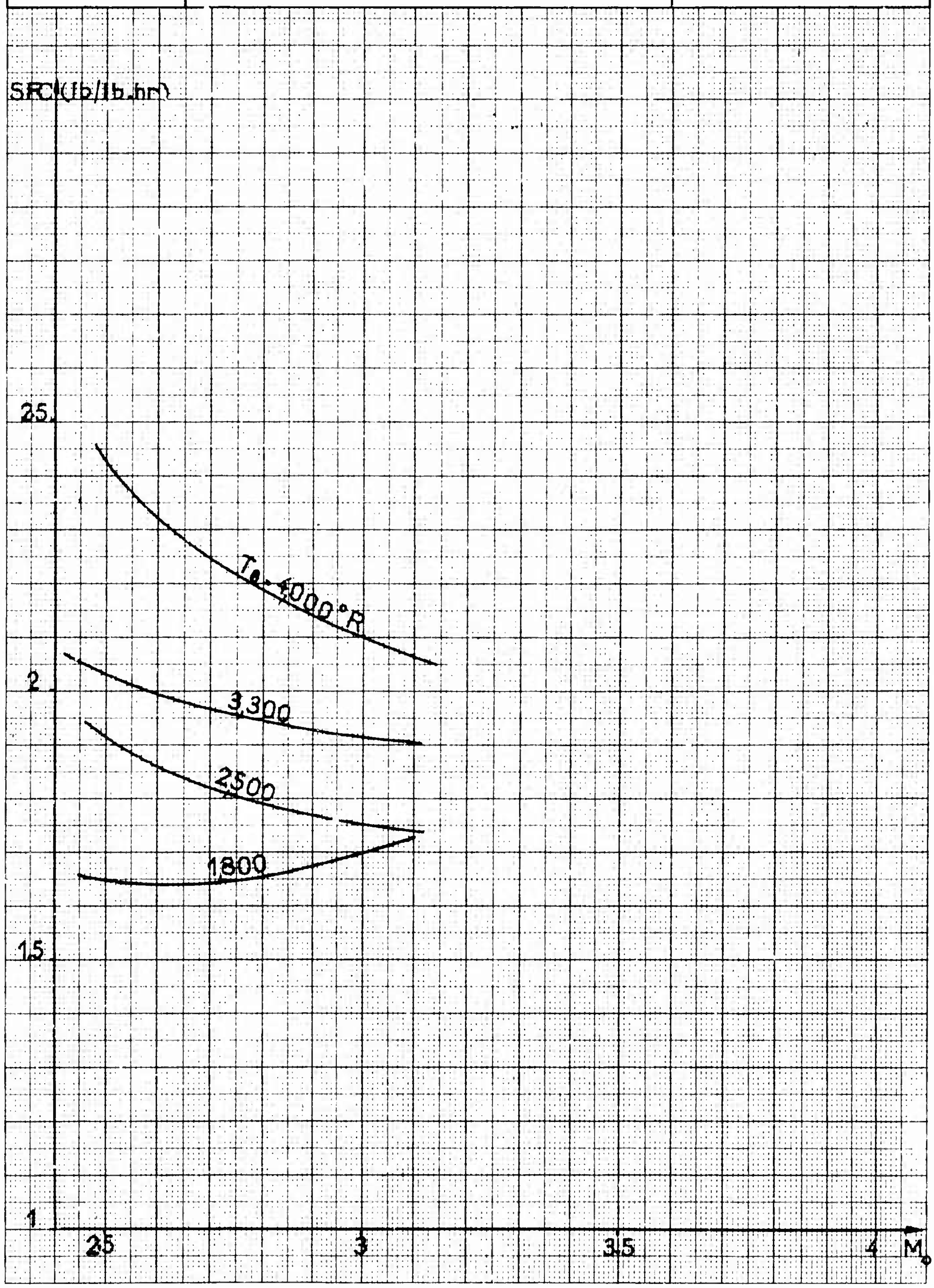
Nord-Aviation	TURBOFAN-RAMJET OPERATION AIR CAPTURE AREA	5152/NIOBE IV/34/Z Figure 111



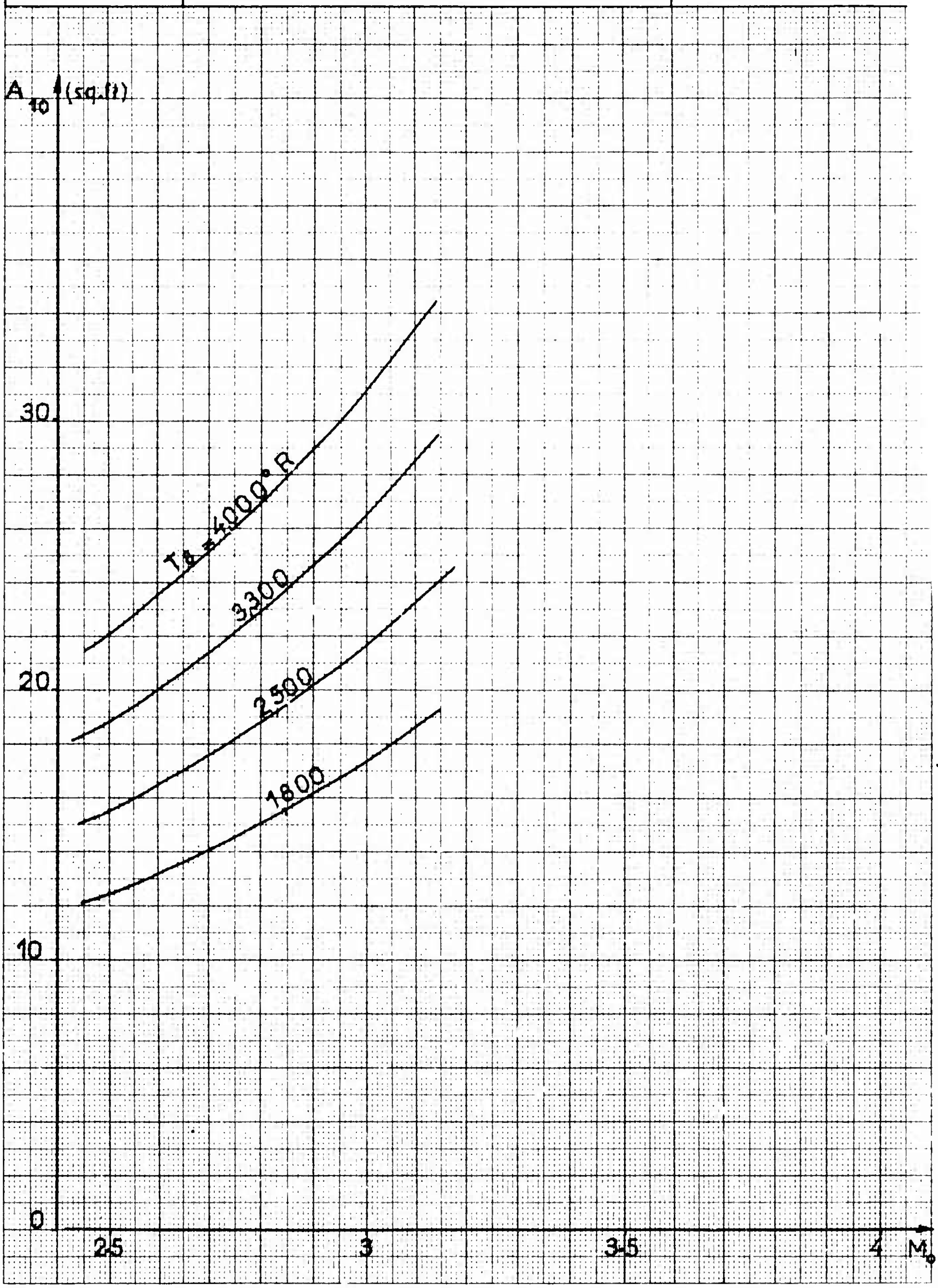
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 50 000 ft	5152/NIOBE IV/34/Z Figure 112



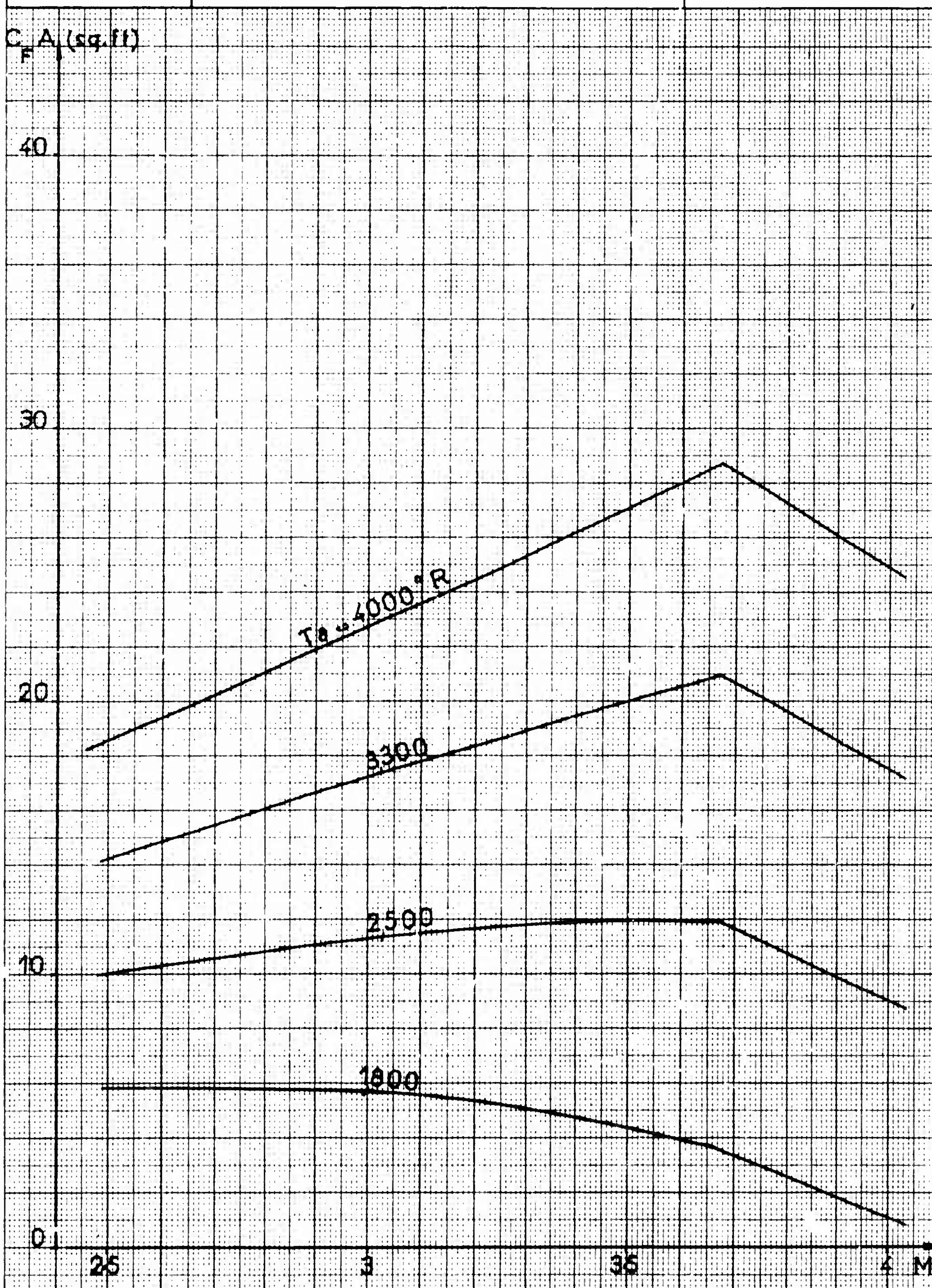
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 50 000 ft	5152/NIOBE IV/34/Z Figure 113



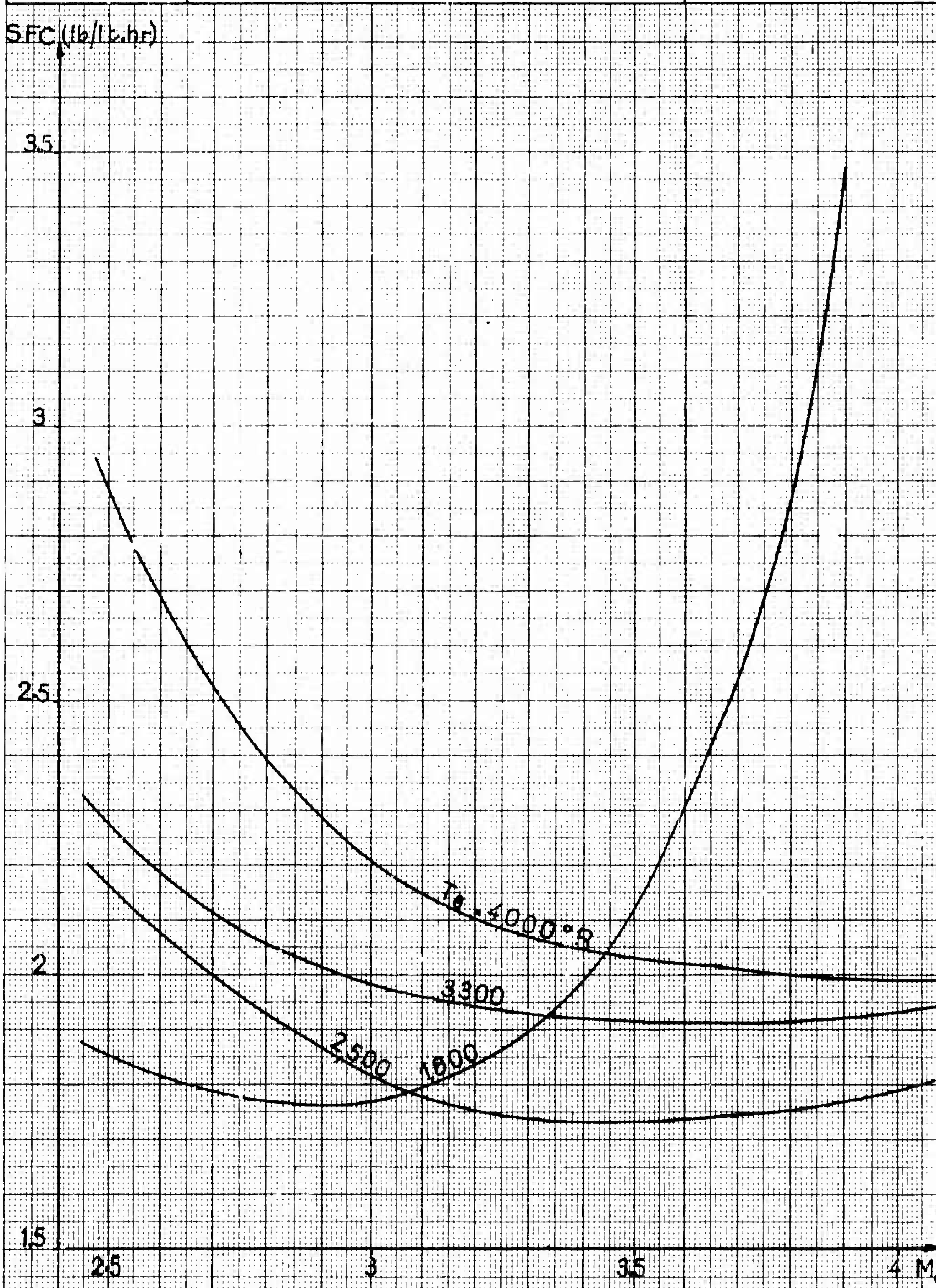
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 50 000 ft	5152/NIOBE IV/34/Z Figure 114



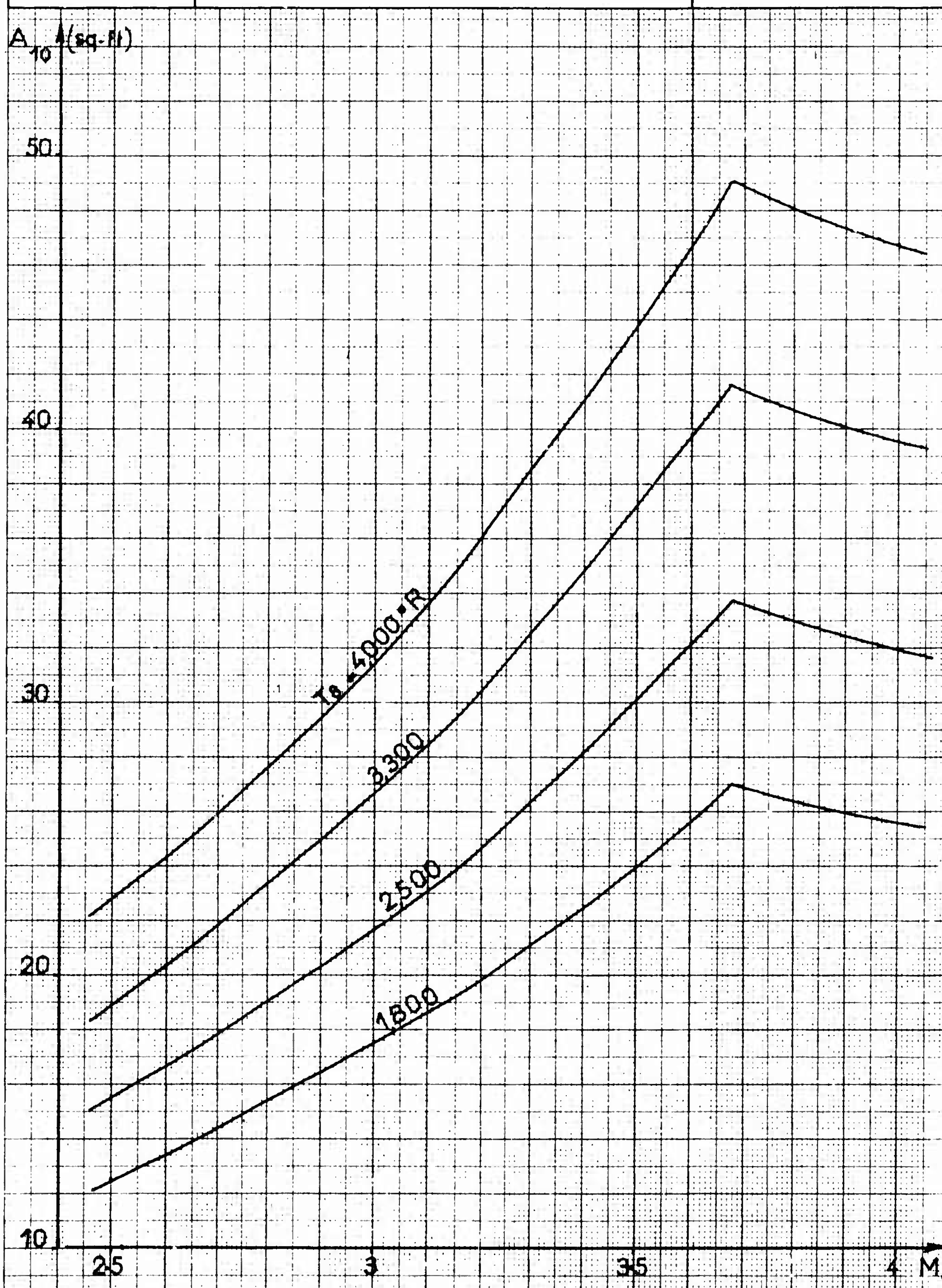
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 75 000 ft	5152/NIOBE IV/34/Z Figure 115



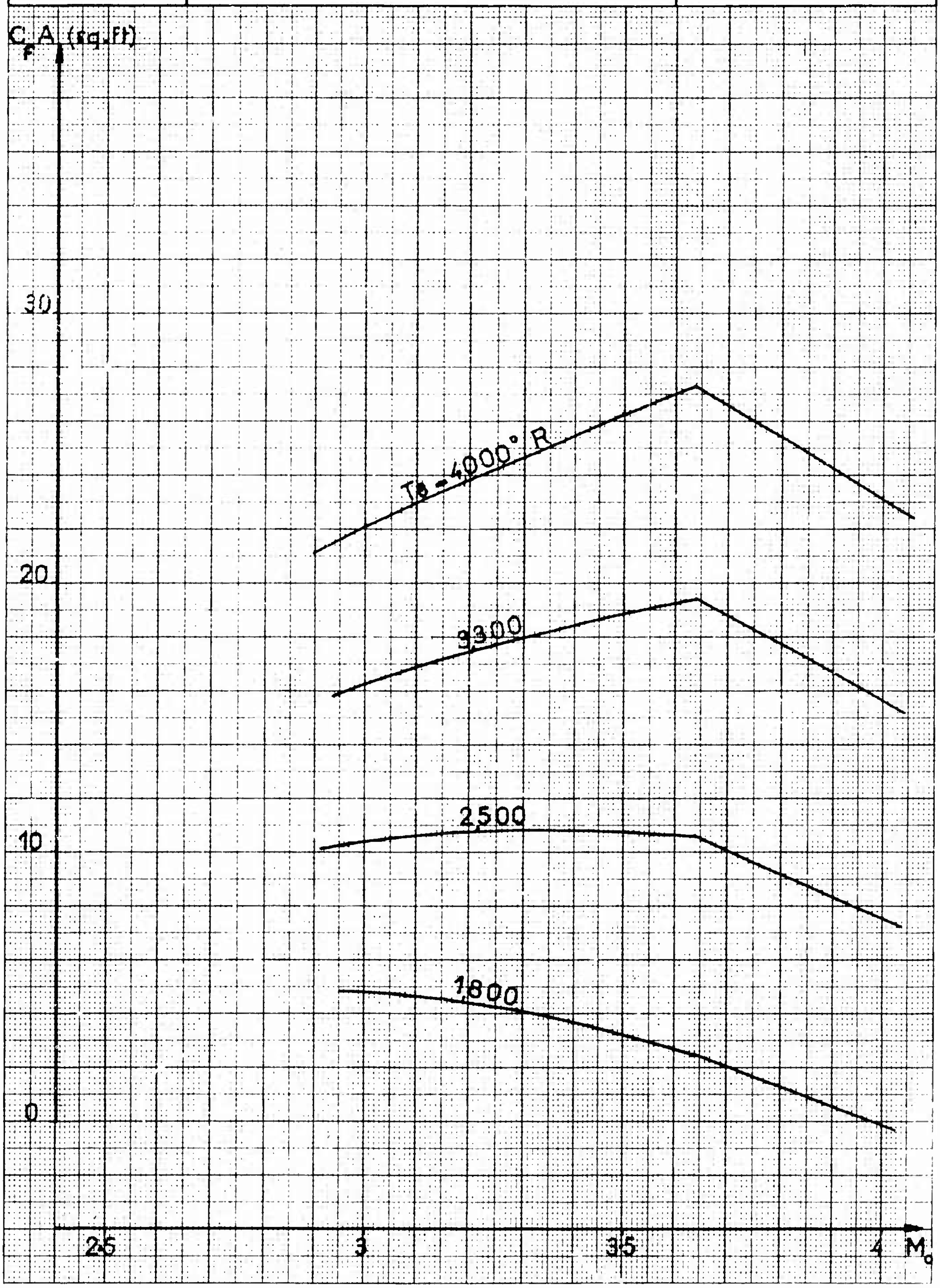
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 75 000 ft	5152/NIOBE IV/34/Z
		Figure 116



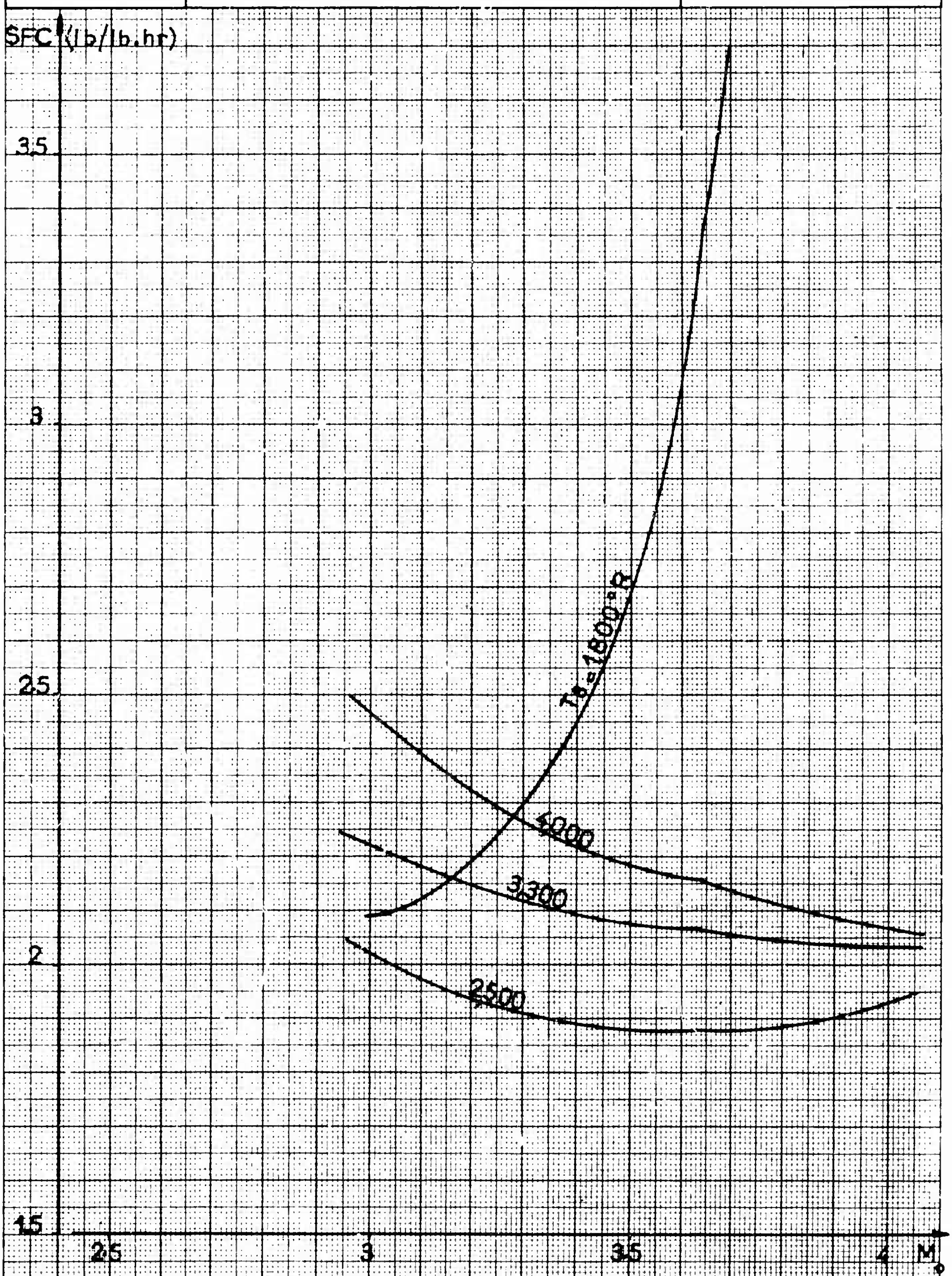
Nord-Aviation	RAMJET OPERATION (Turbofan Stopped) Z = 75 000 ft	5152/NIOBE IV/34/Z Figure 1.[illegible]



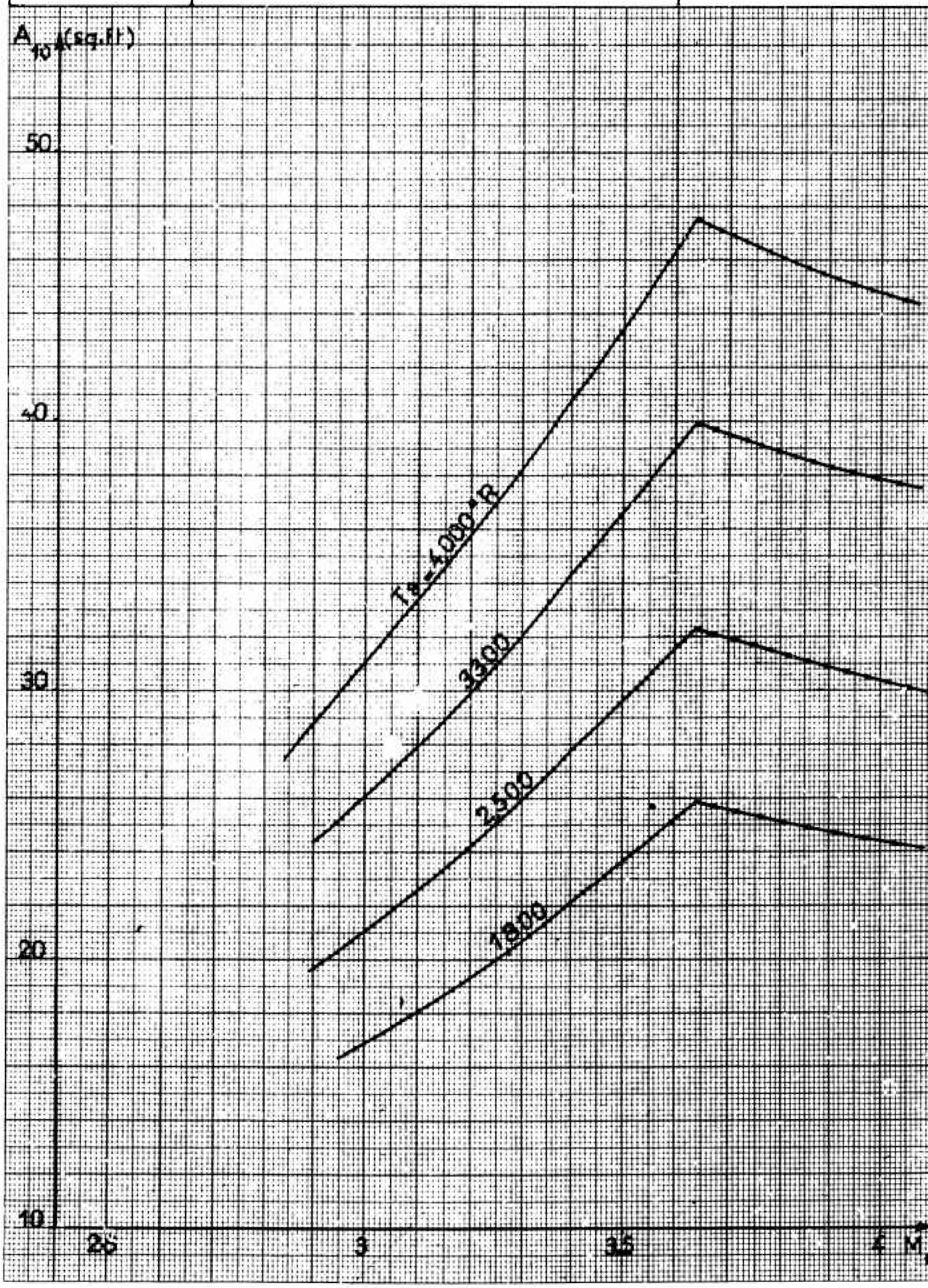
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 100 000 ft	5152/NIOBE IV/34/Z Figure 118



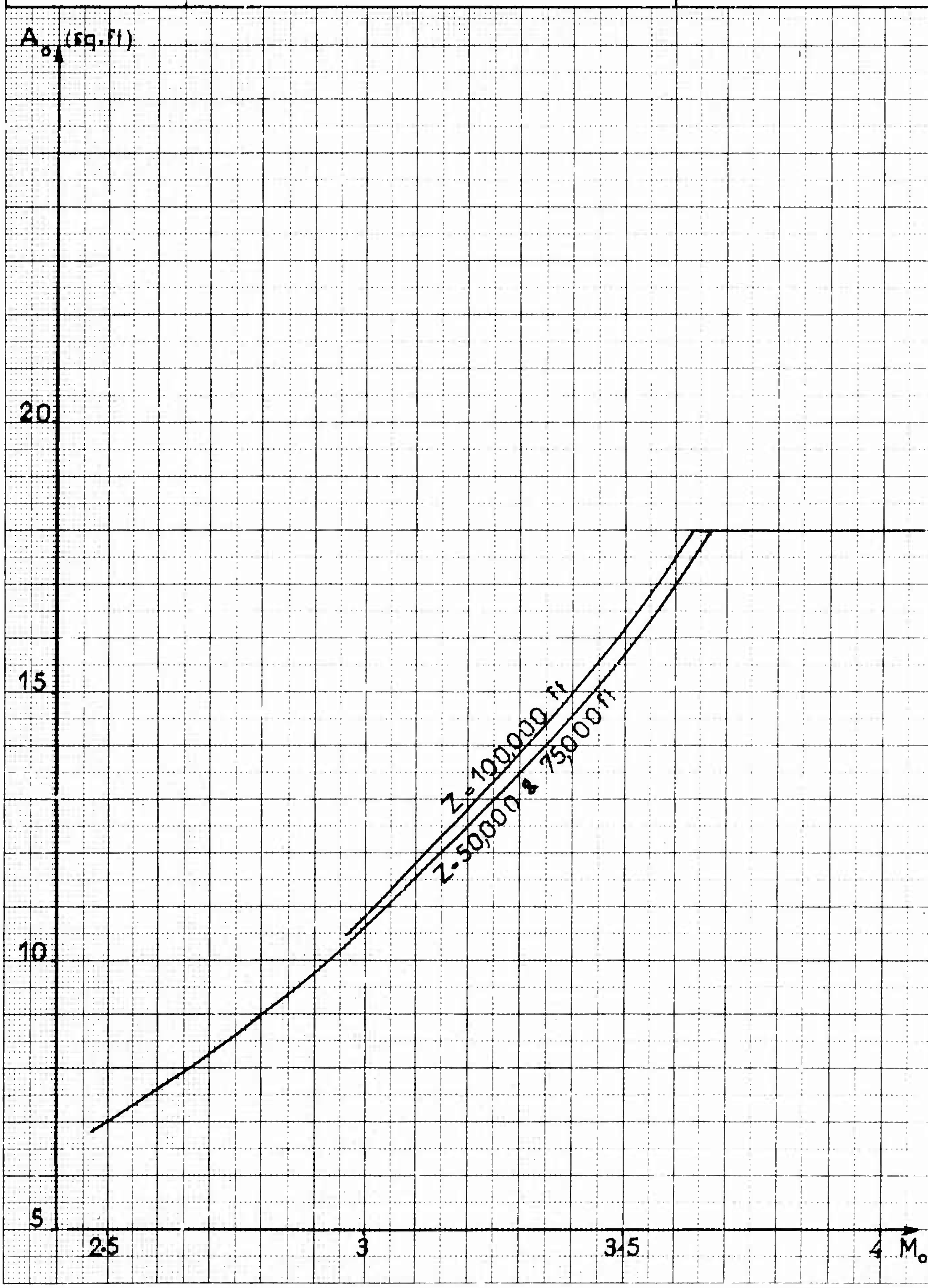
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 100 000 ft	5152/NIOBE IV/34/Z Figure 119



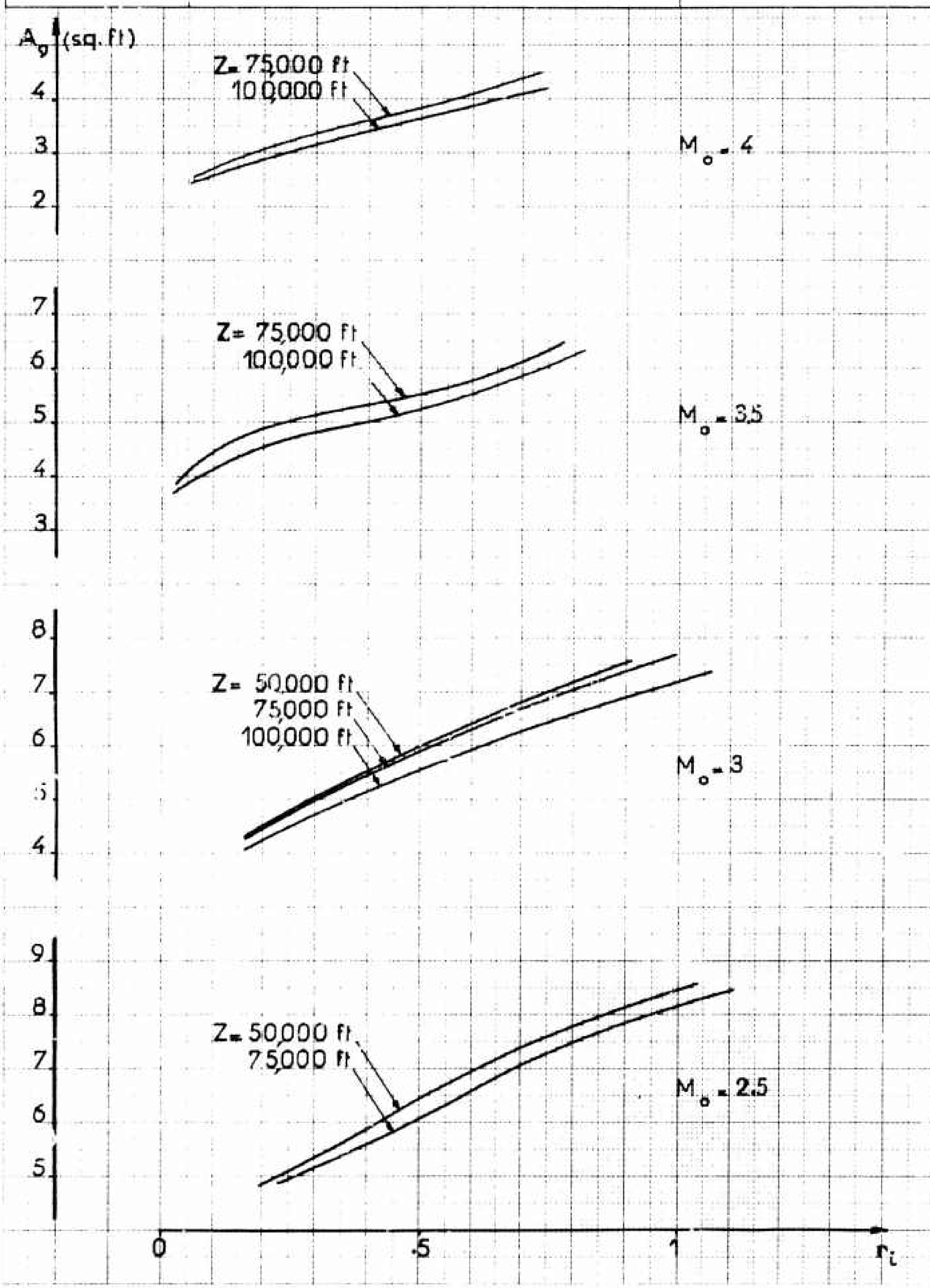
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Z = 100 000 ft	5152/NIOBE IV/34/Z Figure 120



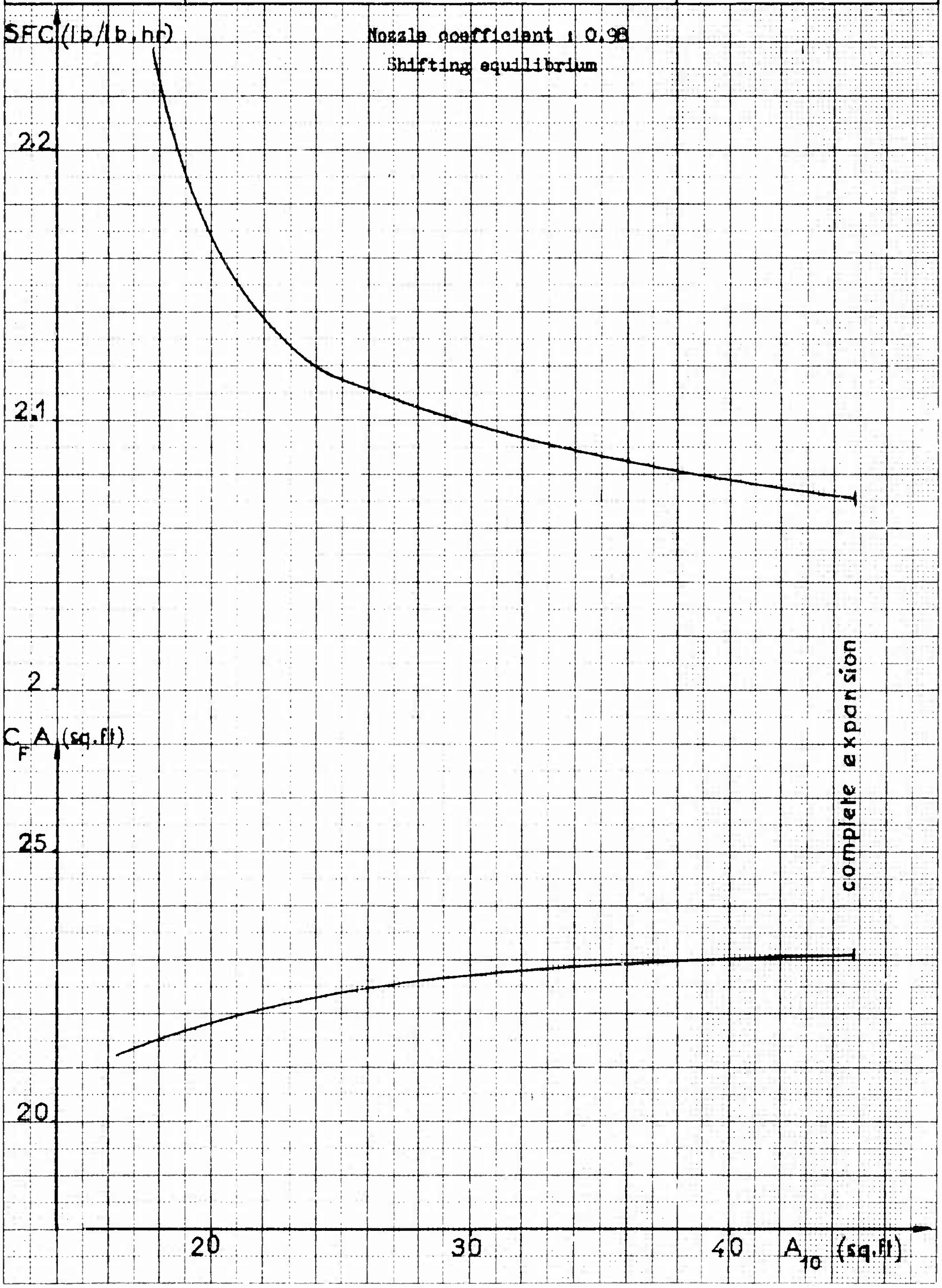
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) AIR CAPTURE AREA	5152/NIOBE IV/34/2 Figure 121



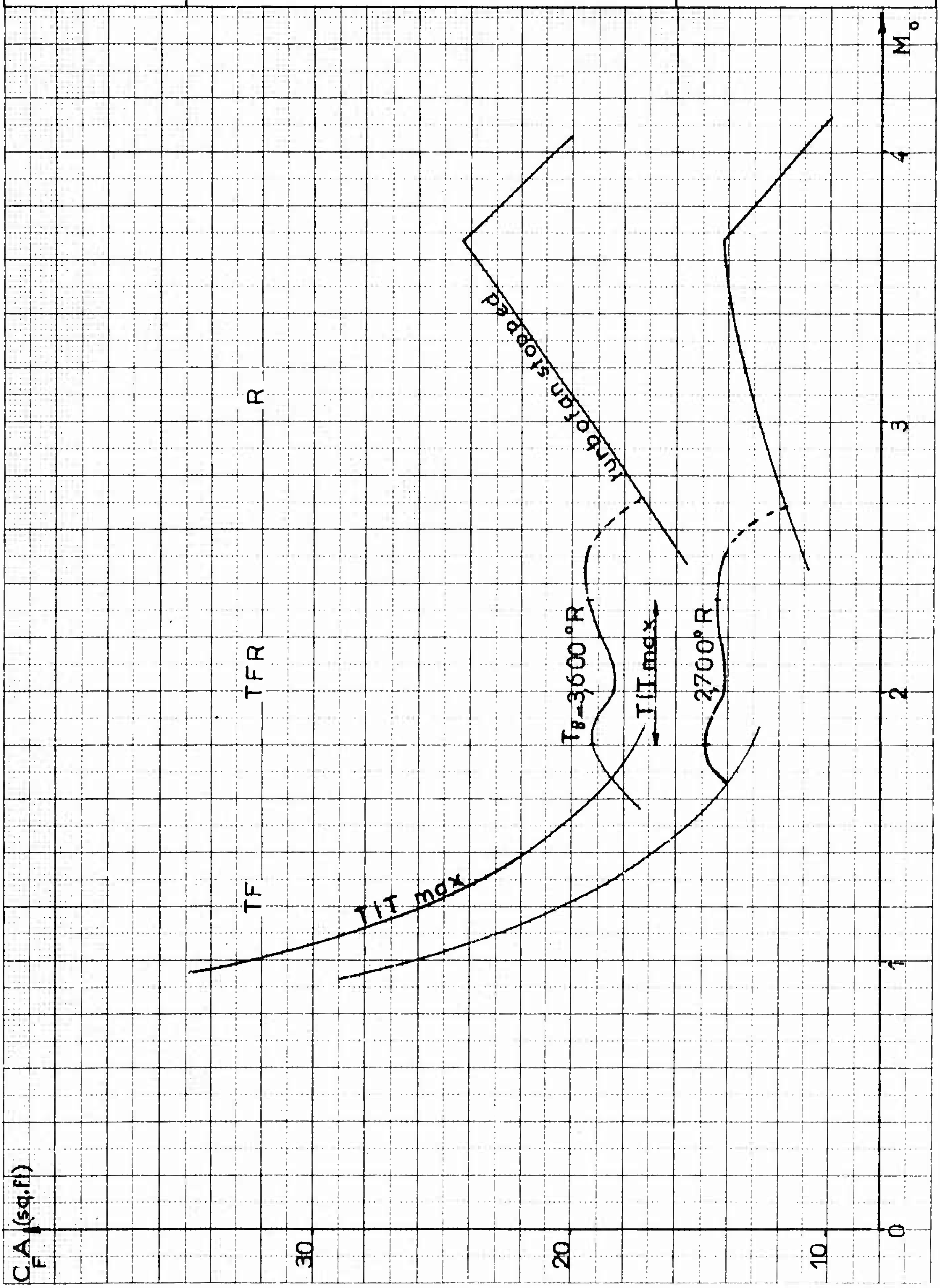
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Nozzle throat and fuel control	5152/N10TE IV/34/Z Figure 122



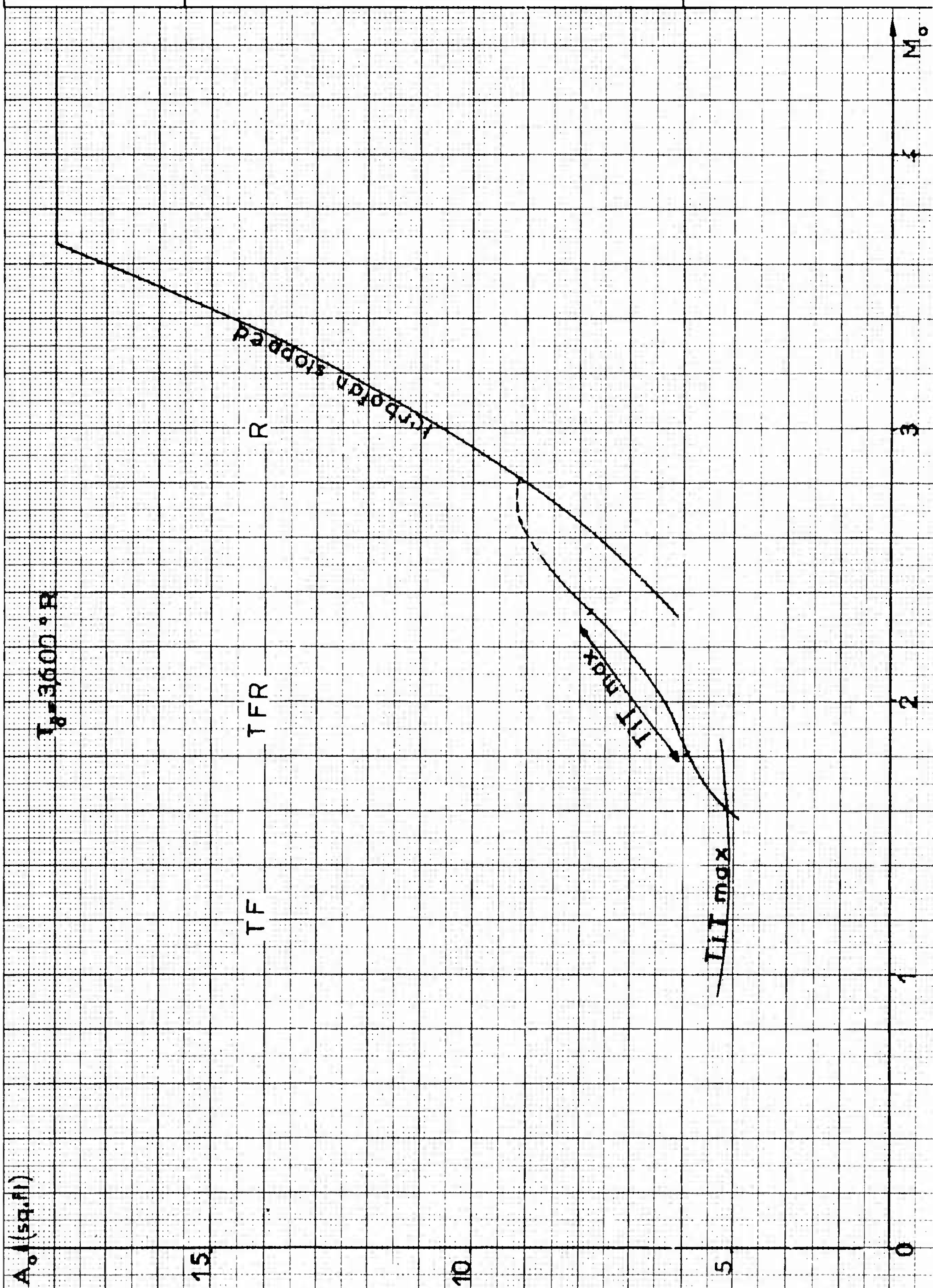
Nord-Aviation	RAMJET OPERATION (Turbofan stopped) Mo = 4 Z = 100 000 ft T_8 = 4 000 °R	5152/NIOBE IV/34/Z Figure 123



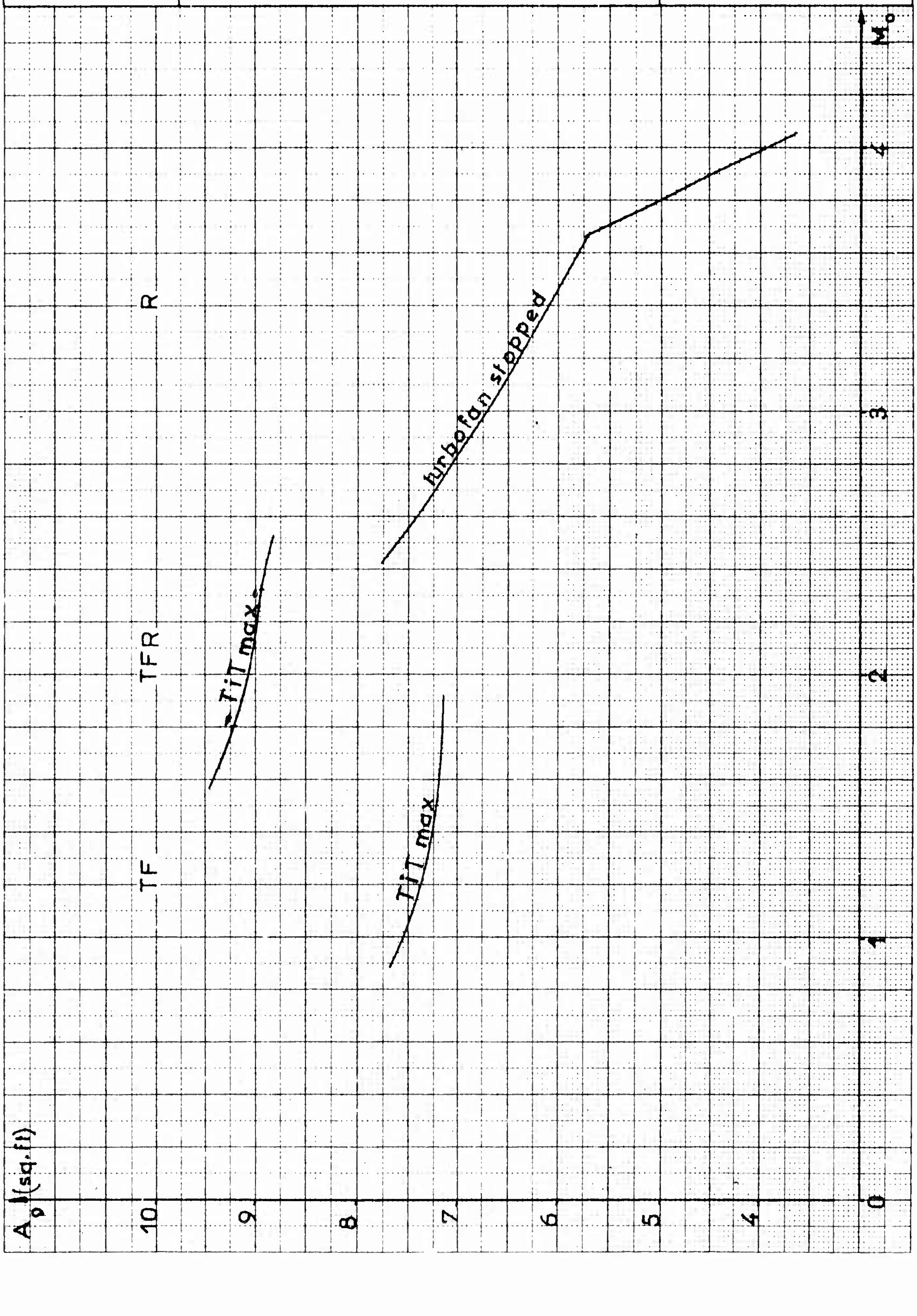
Nord-Aviation	TRANSONIC AND SUPERSONIC ACCELERATION $36\,000 \text{ ft} \leq Z \leq 82\,000 \text{ ft}$	5152/NIOBE IV/34/Z Figure 124



Nord-Aviation	AIR CAPTURE AREA 36 000 ft $\leq$ Z $\leq$ 82 000 ft	5152/NIOBE IV/34/Z Figure 125



Nord-Aviation	EXIT NOZZLE THROAT AREA 36 000 ft $\leq Z \leq$ 82 000 ft T_{t4} = 3 600 °R	5152/NIOBE IV/34/Z Figure 126



AF 61 (052)_750

5153/NIOBE IV/35/Z

December 1965

FINAL REPORT

EXPERIMENTAL AND DESIGN STUDIES

FOR TURBO-RAMJET COMBINATION ENGINE

Volume 4-2 : INTERNAL FLOW CHARACTERISTICS

NORD-AVIATION

DEPARTEMENT 'PROPULSEURS'

PARIS(CHATILLON) FRANCE

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SUMMARY

In this volume, we have produced the values of pressures, temperatures and Mach numbers at different levels, under accelerating working conditions, for operations as a pure turbofan, as a turbofan-ramjet combination engine, and as a pure ramjet.

These values have directly proceeded from the performance characteristics computations carried out on the IBM 7040 computer (see Vol. 2 - CALCULATION ANALYSIS).

CONTENTS

LIST OF FIGURES

SYMBOLS

Superscripts

' Indicatos turbofan primary flow parameters

" Indicates combination engine annular flow parameters

Subscripts

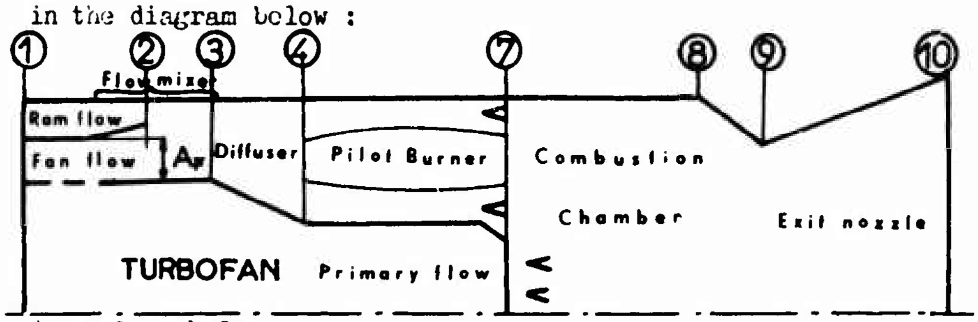
R Ramjet flow

T Turbofan total flow

F Turbofan secondary flow

o Refers to parameters at upstream infinite

Numerical subscripts refer to various stations as indicated in the diagram below :



General symbols

A Cross-sectional area

P Total pressure

T Total temperature

t Static temperature

M Mach number

D Air flow

τ Flame holder drag coefficient

$\sigma = A_{F2} / A''_3$

γ Isentropic coefficient

TF operation : Turbofan operation

TFR operation : Turbofan-ramjet operation

R operation : Ramjet operation

TIT : Turbine inlet temperature

1 - GENERAL

In this document we have produced the variation ranges of pressure, temperature and speed within the X 81 combination engine when operating under accelerating conditions.

In TF operation, the results we have given have reference to the turbofan maximum rating, in both cases "without", or "with" afterburning (T_8 = 3,600 °R).

In TFR operation, the results produced refer to temperatures T_8 = 2,700 °R and T_8 = 3,600 °R. The turbofan rating is maximum when $1,8 < M_o < 2.3$. If $M_o < 1.8$, the turbofan is slowed down, since TFR operation is not possible at maximum rating ; furthermore this slackening makes the transition easier from TF to TFR operation. In the case when $M_o > 2.3$, the turbofan rating is as well slowed down, so as not to exceed, in the combustion chamber the pressure and temperature-limits fixed by SNECMA.

In R operation, the turbofan is stopped, and temperature T_8 varies between 1,800 °R and 4,000 °R.

Among these results, we have, in particular, given the internal flow characteristics in the following sections :

- A_{T1} : Turbofan inlet
- A_{F2} : Fan exit
- A''_4 : Pilot burner inlet
- A'_7 : Primary exit
- A_8 : Rear extremity of the combustion chamber

Within the case of TFR operation, that is with Mach number comprised between 1.6 and 2.5, we have also given the variation range of σ, while the TFR operating range being

limited by $M_{R2} = 0.1$ and $A_9/A_8 = 0.75$.

The values relating to the internal flow have been obtained parallely with the results concerning the performance characteristics, by the computation method defined in Vol. 2 - CALCULATION ANALYSIS.

2 - AIR INLET PRESSURE RECOVERY

The control of the outlet section and the engine regulation are such that the air inlet operates at its maximum recovery ratio for all running conditions of the turbofan and ramjet.

In Fig. 1 we have plotted the air inlet efficiency in terms of the flight Mach Number.

3 - TOTAL TEMPERATURE AT THE ENGINE INLET

The operating curves of turbofan SNECMA TF 106 have been supplied by the manufacturer for certain values of the total temperature at the engine inlet.

Knowing this temperature T_1 determines, in the case of TF or TFR operation,

- either altitude Z in terms of the flight Mach number when $Z \leq 36{,}000$ ft ($t_o = f(Z)$)
- or the flight Mach number when $36{,}000 < Z < 82{,}000$ ft (t_o = a constant), namely :

for T_1 =	648 °R	: M_o =	1.82
"	702	: "	2
"	810	: "	2.32

.../..

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For T_1 = 990 °R, the calculations related to TFR operation were carried out with subjecting the turbofan to a reduced rating (TIT/TIT_{max} = 0.9), so as not to exceed the pressure and temperature limitations fixed by SNECMA, which corresponds to M_o = 2.536.

Fig. 2 is an illustration of the curve $T_1(M_o, Z)$.

4 - PRESSURES

Inside the combination engine, the pressure levels it is important to know are the following :

- P_1 : turbofan inlet total pressure
- P_{F2} : secondary exit total pressure
- P''_4 : pilot burner inlet total pressure
- P'_7 : primary exit total pressure
- P_8 : nozzle inlet total pressure

It should be remembered that

- pressure P''_4 is used (with T''_3) when calculating the combustion efficiency in the annular chamber ;

- due to the interaction between primary and annular flows, the pressures P'_7 and P_{F2} in TF operation, P'_7 and P''_4 in TFR operation, should be nearly equal ;

- pressure P_8 plays an important part in the definition of the exit nozzle.

In Fig. 3,4,5 and 6, we have respectively plotted the pressures P_{F2}, P''_4, P'_7 and P_8 referred to pressure P_1.

5 - TEMPERATURES

According to the calculation diagram, the only total temperature variations occur in the flow mixer and the combustion chamber.

.../..

Therefore the characteristics temperature levels are :

T_1 : turbofan inlet total temperature
T_{F2} : fan exit total temperature
T''_4 : pilot burner inlet total temperature
T'_7 : primary exit total temperature
T_8 : total temperature at the rear extremity of the combustion chamber

In Fig.7, 8, 9, we have plotted the curves of temperatures T_{F2}, T''_4 and T'_7.

6 - VELOCITIES

In order to permit a satisfactory combustion, the Mach numbers in sections A''_4 and A'_7 must be rather low. These velocities, M'_7 and M''_4, are also used when calculating the drag coefficients of the flame holders.

The Mach number at the rear end of the combustion chamber has been used for the exit nozzle calculation.

In Fig. 10, 11, and 12, we have respectively plotted the values of M''_4, M'_7 and M_8.

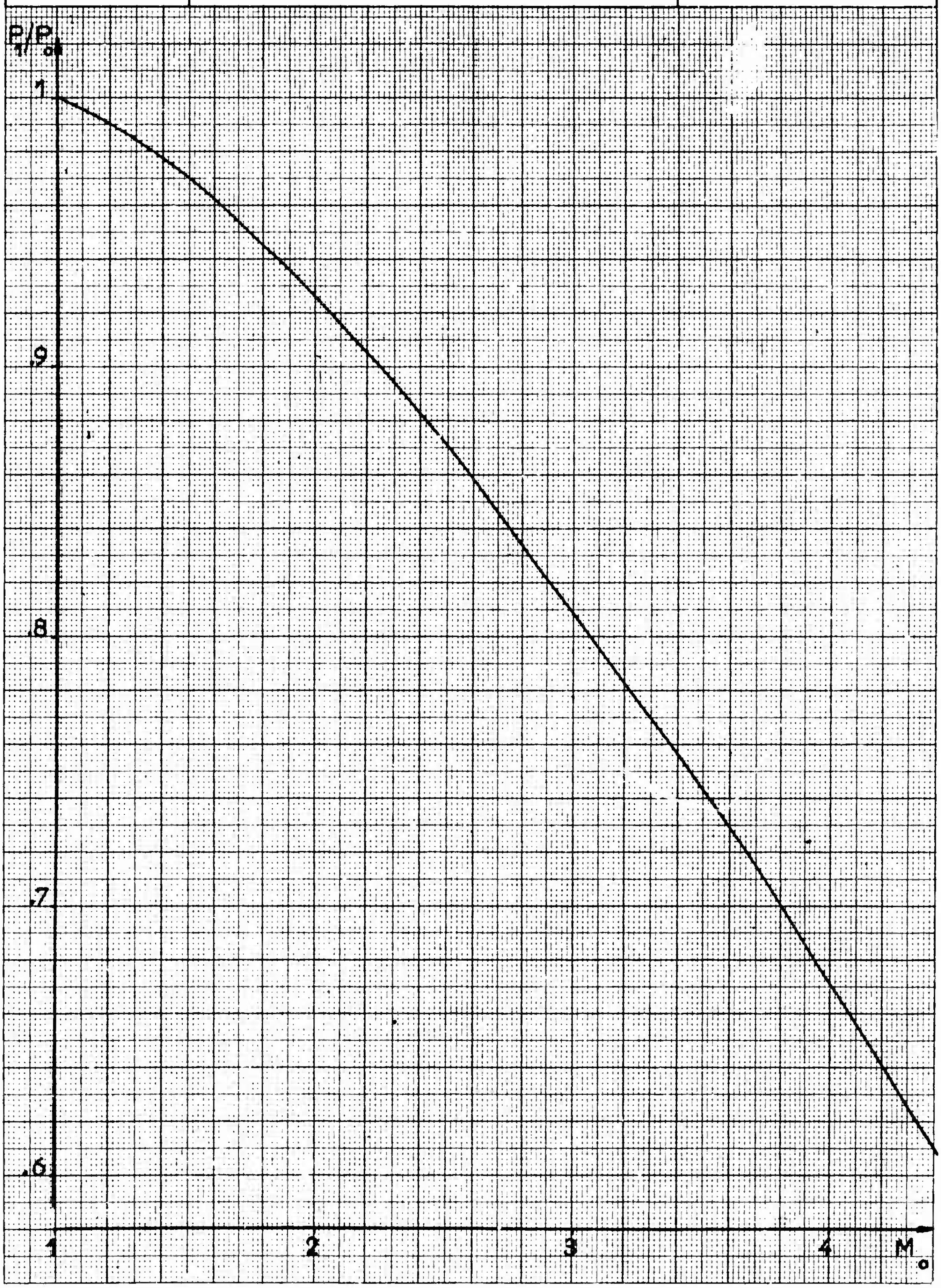
7 - FLOW RATIOS

In Fig. 13, we have plotted the ratio between primary and annular flows, D' / D''.

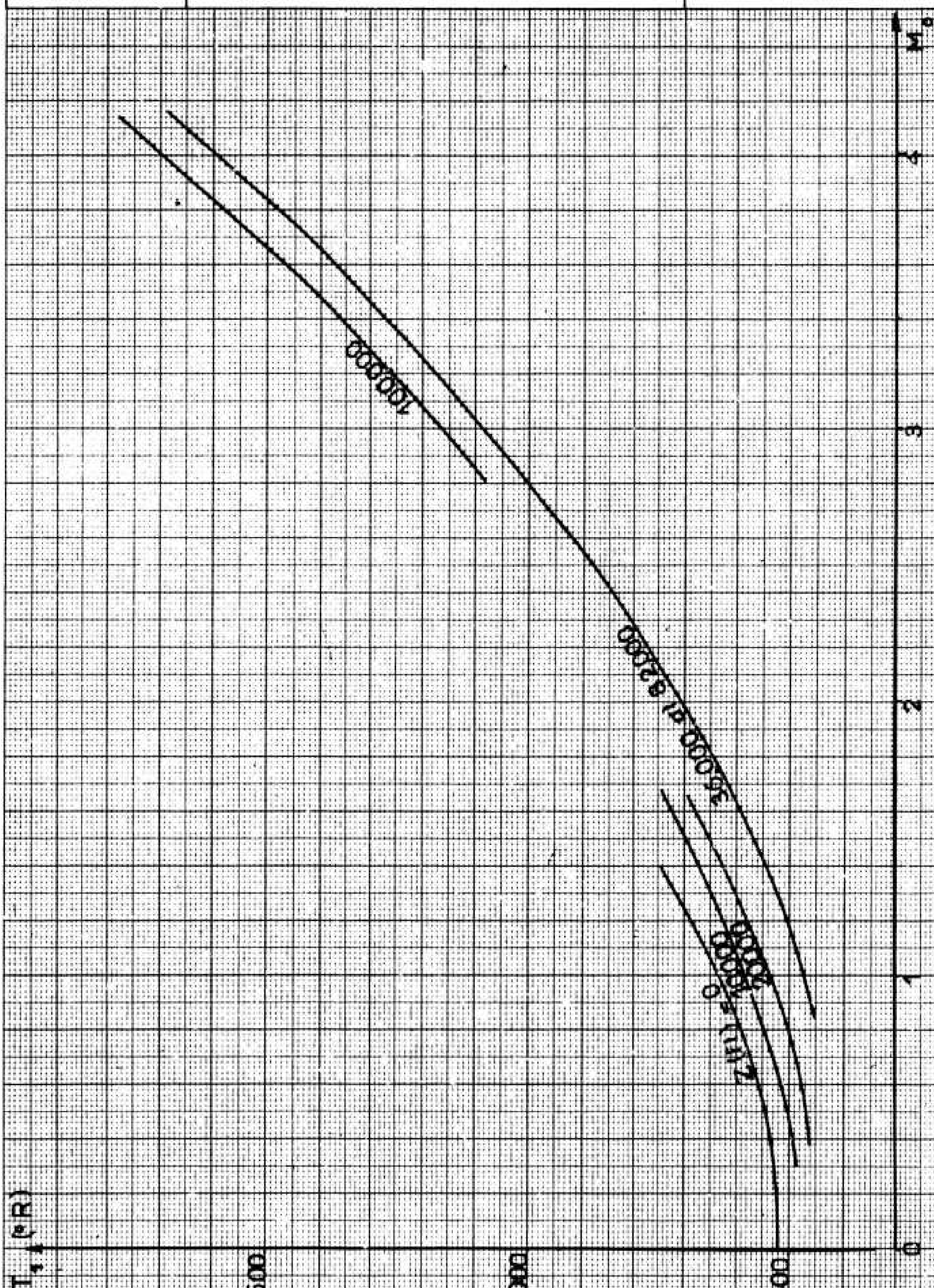
8 - FLOW MIXER

As concerns TFR operation, that is for Mach numbers comprised between 1.6 and 2.5, Fig. 14 illustrates the variations of $\sigma = A_{F2} / A''_3$.

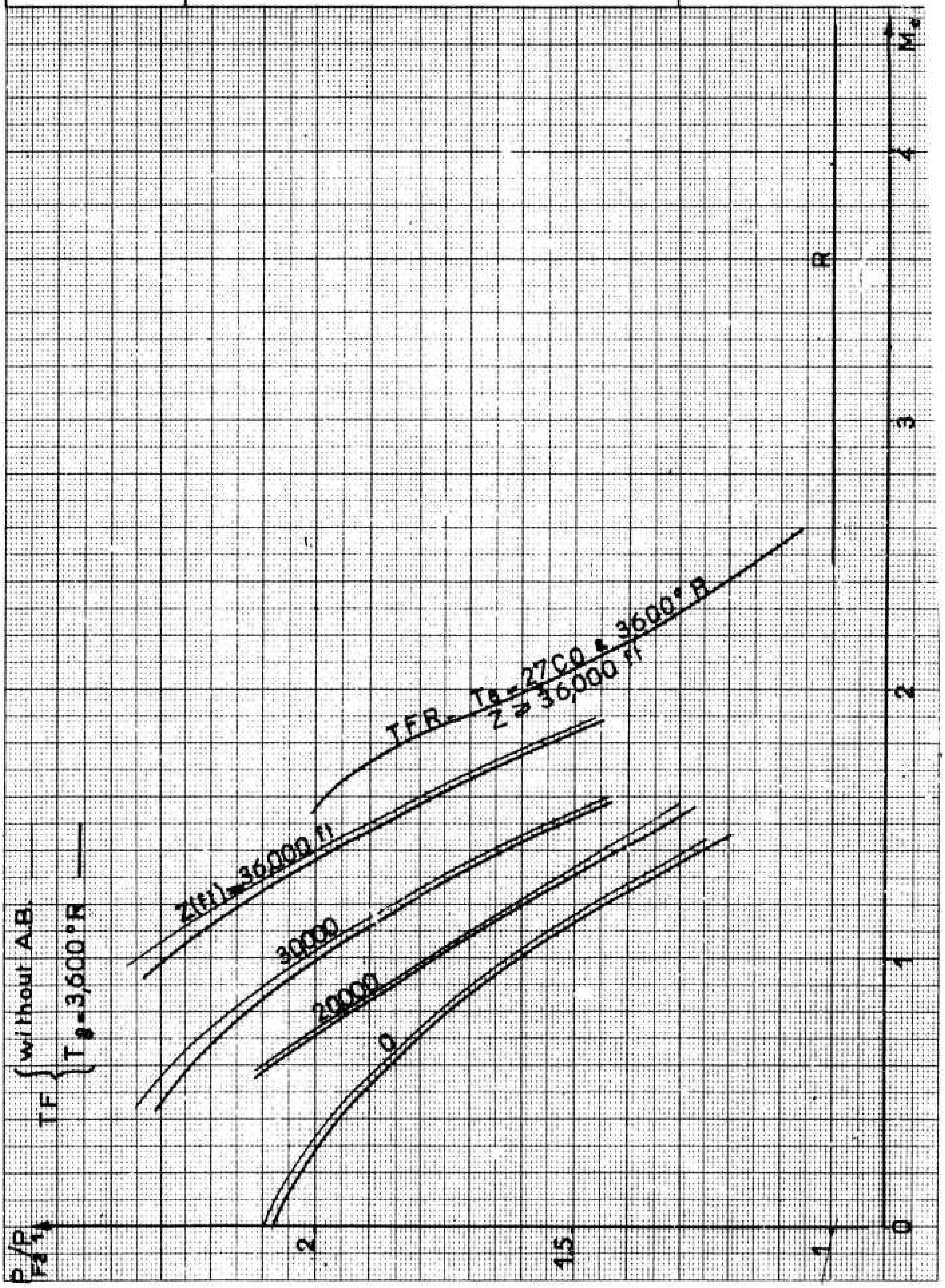
Nord-Aviation	AIR INLET PRESSURE RECOVERY	5153/NIOBE IV/35/Z **Figure 1**



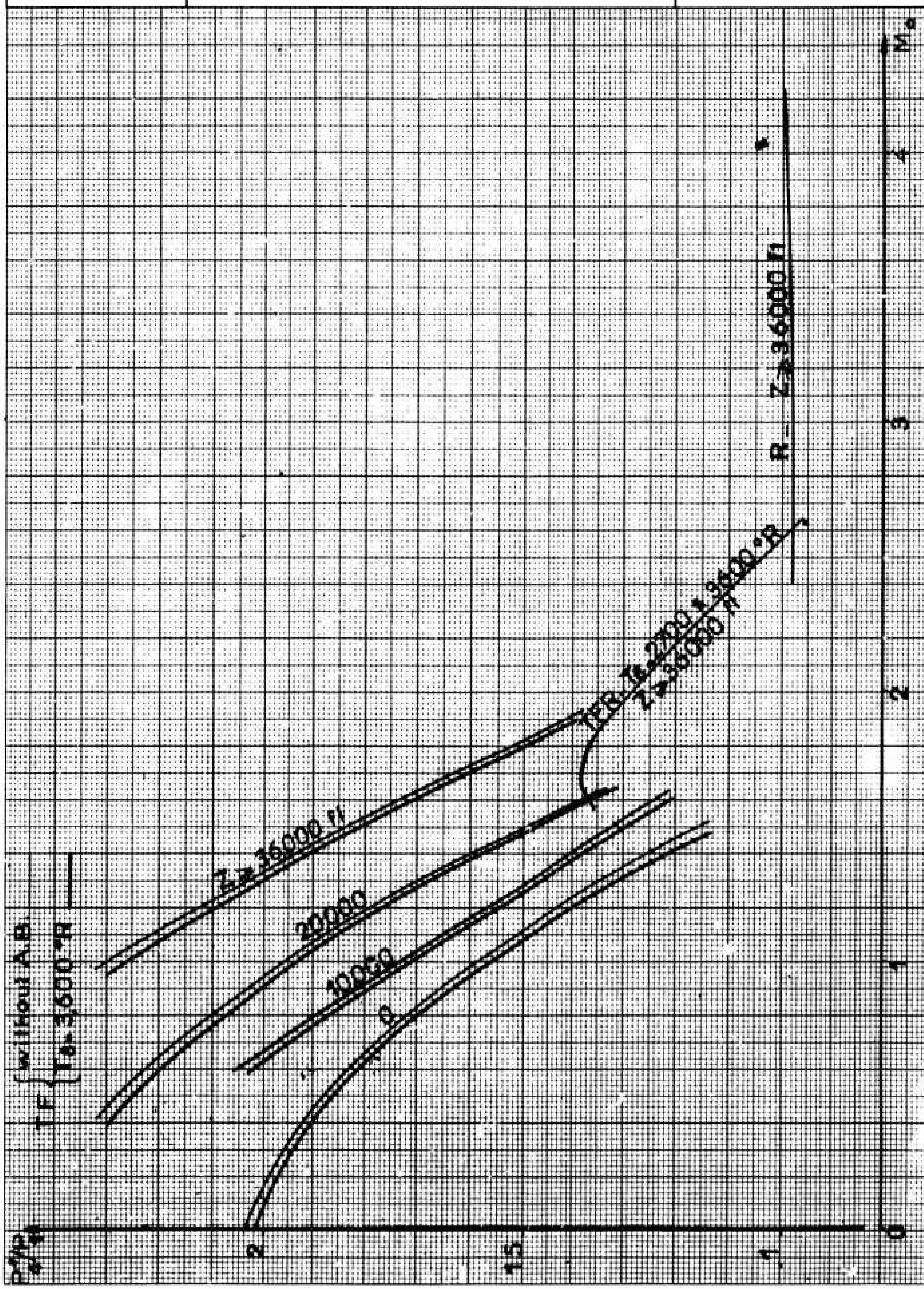
Nord-Aviation	INLET TOTAL TEMPERATURE	5153/NIOBE IV/35/Z Figure 2



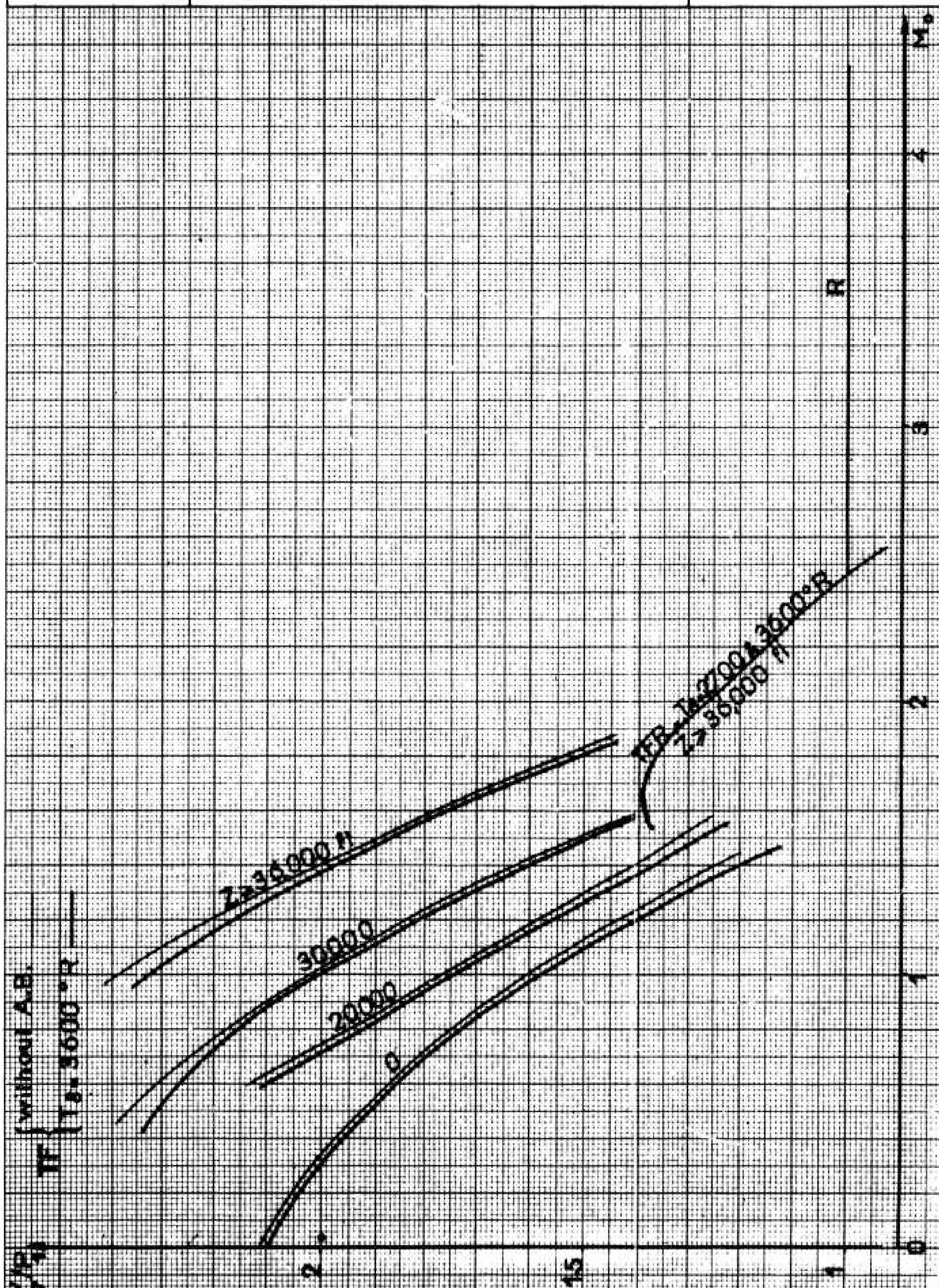
Nord-Aviation	FAN PRESSURE RATIO	5153/NIOBE IV/35/Z Figure 3



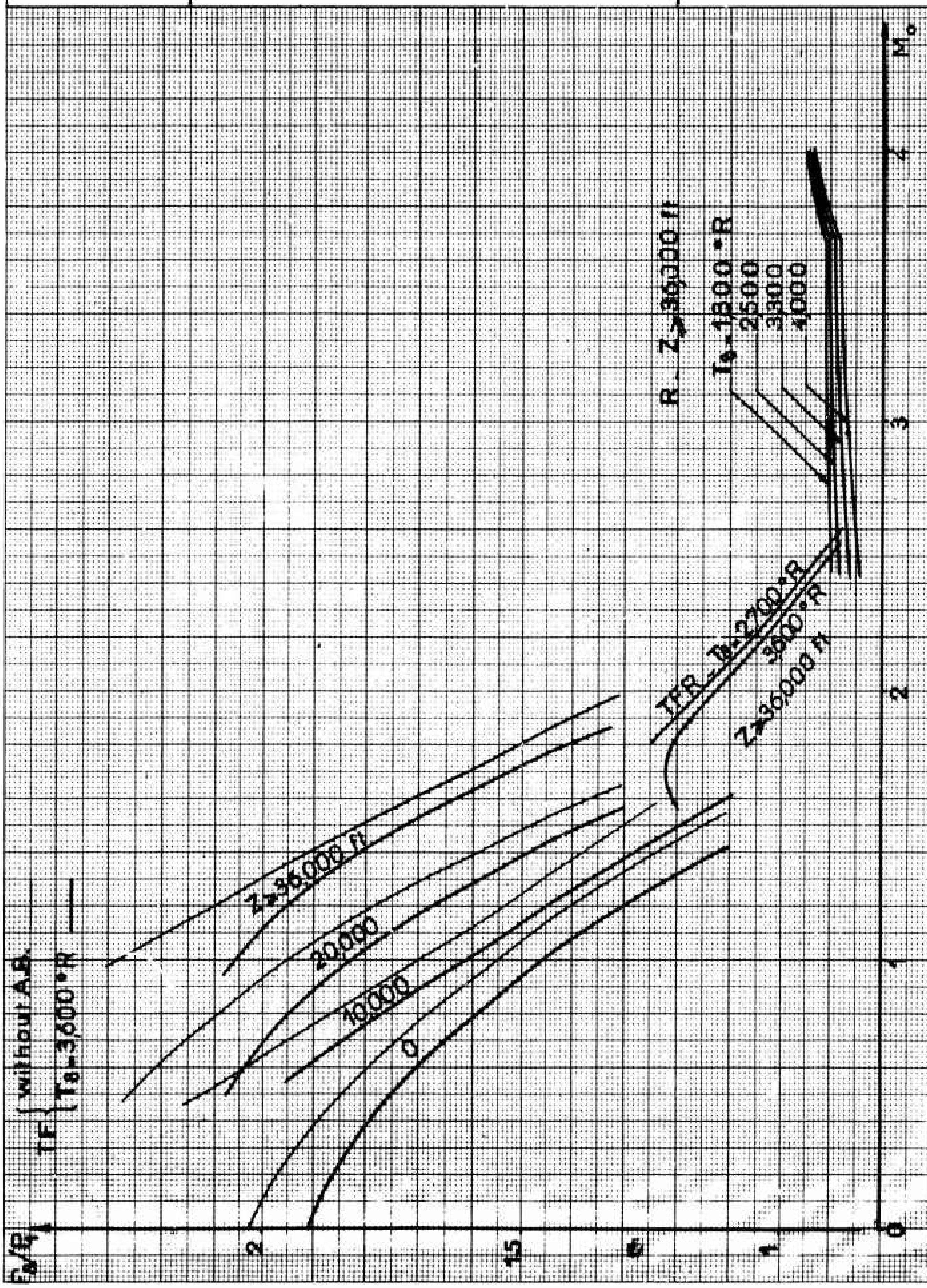
Nord-Aviation	PILOT BURNER INLET PRESSURE RATIO	5153/NIOBE IV/35/Z Figure 4



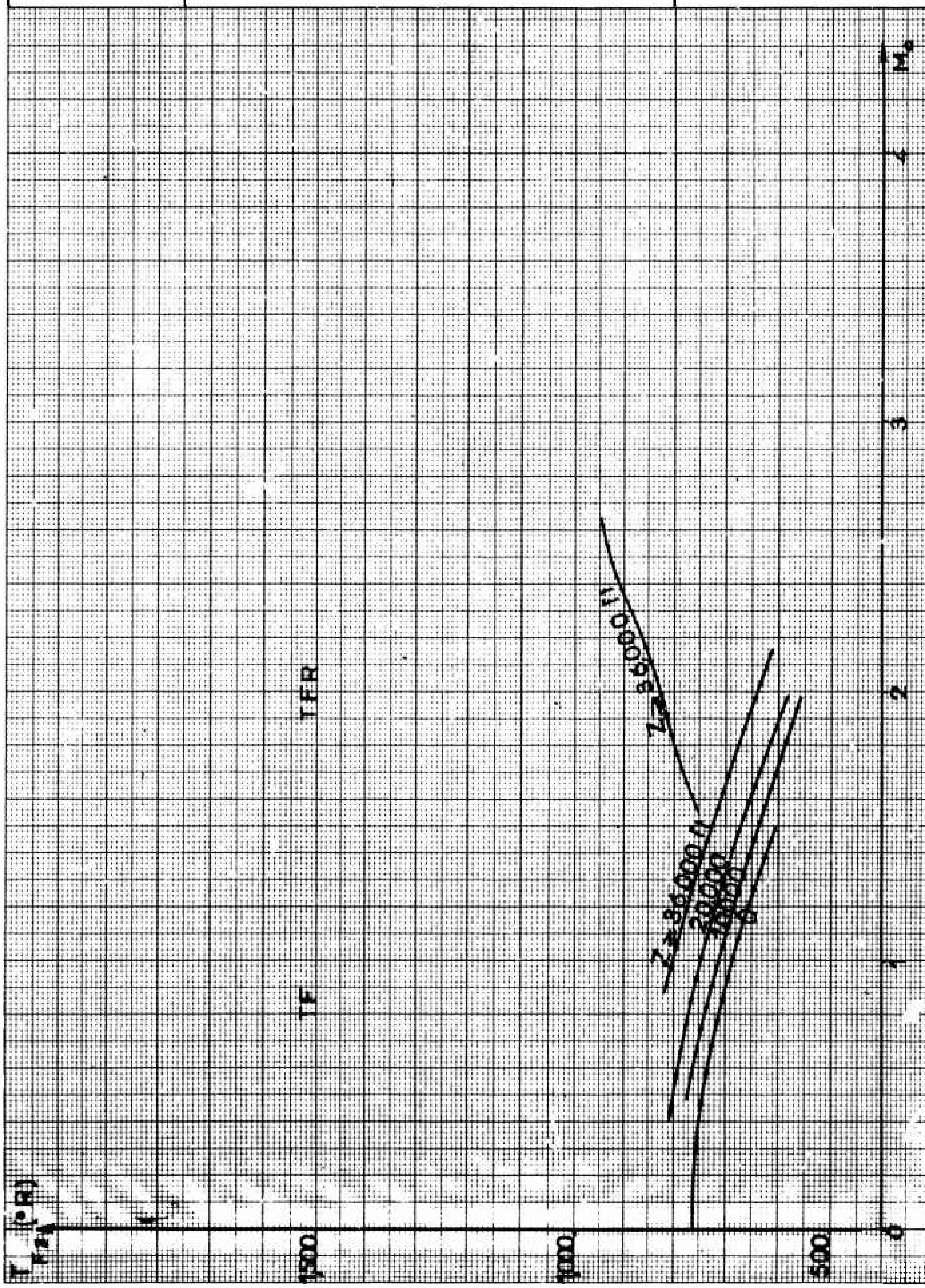
Nord-Aviation	PRIMARY EXIT PRESSURE RATIO	5153/NIOBE IV/35/Z
		Figure 5



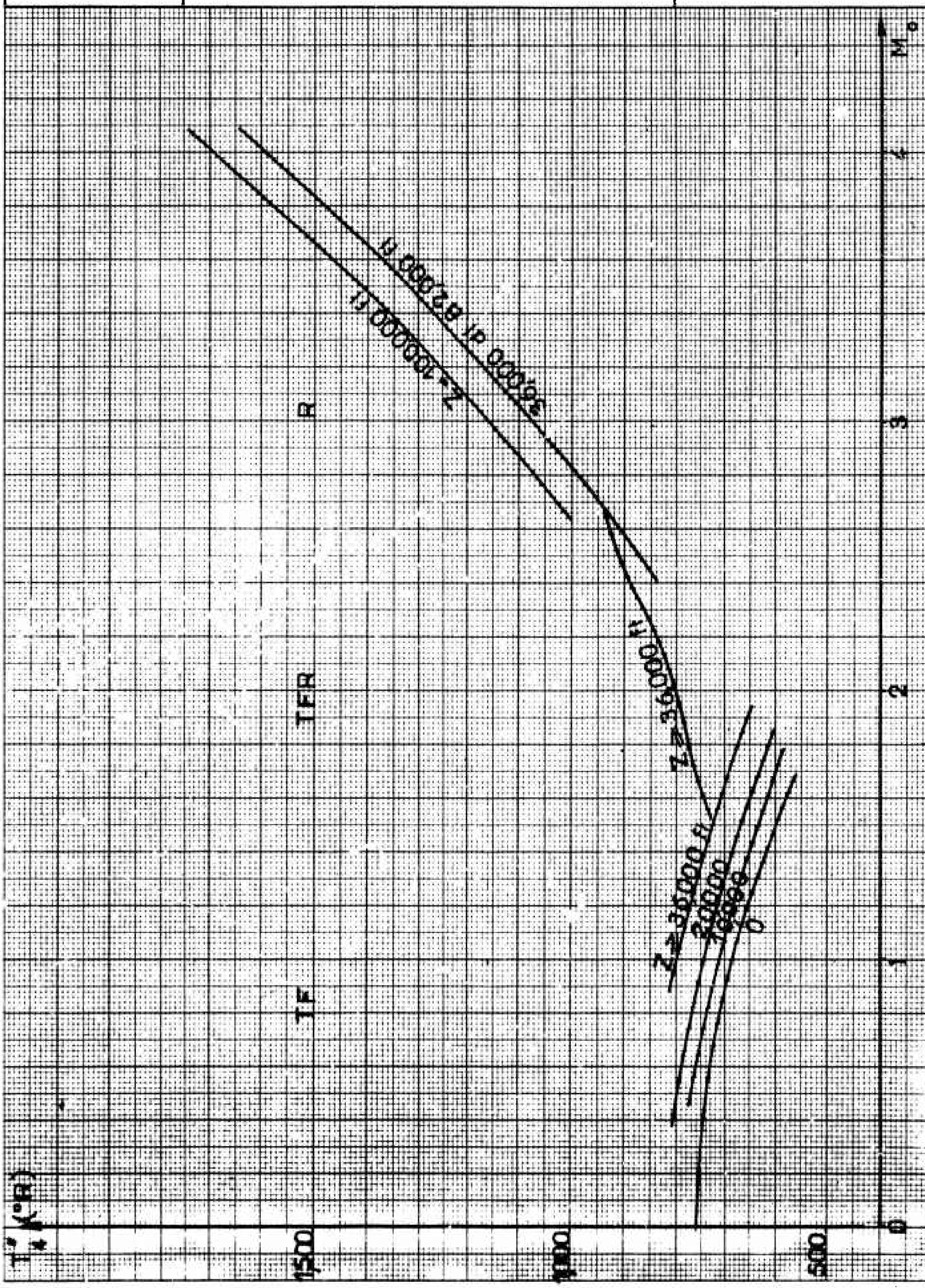
Nord-Aviation	OVERALL PRESSURE RATIO	5153/NIOBE IV/35/Z
		Figure 6



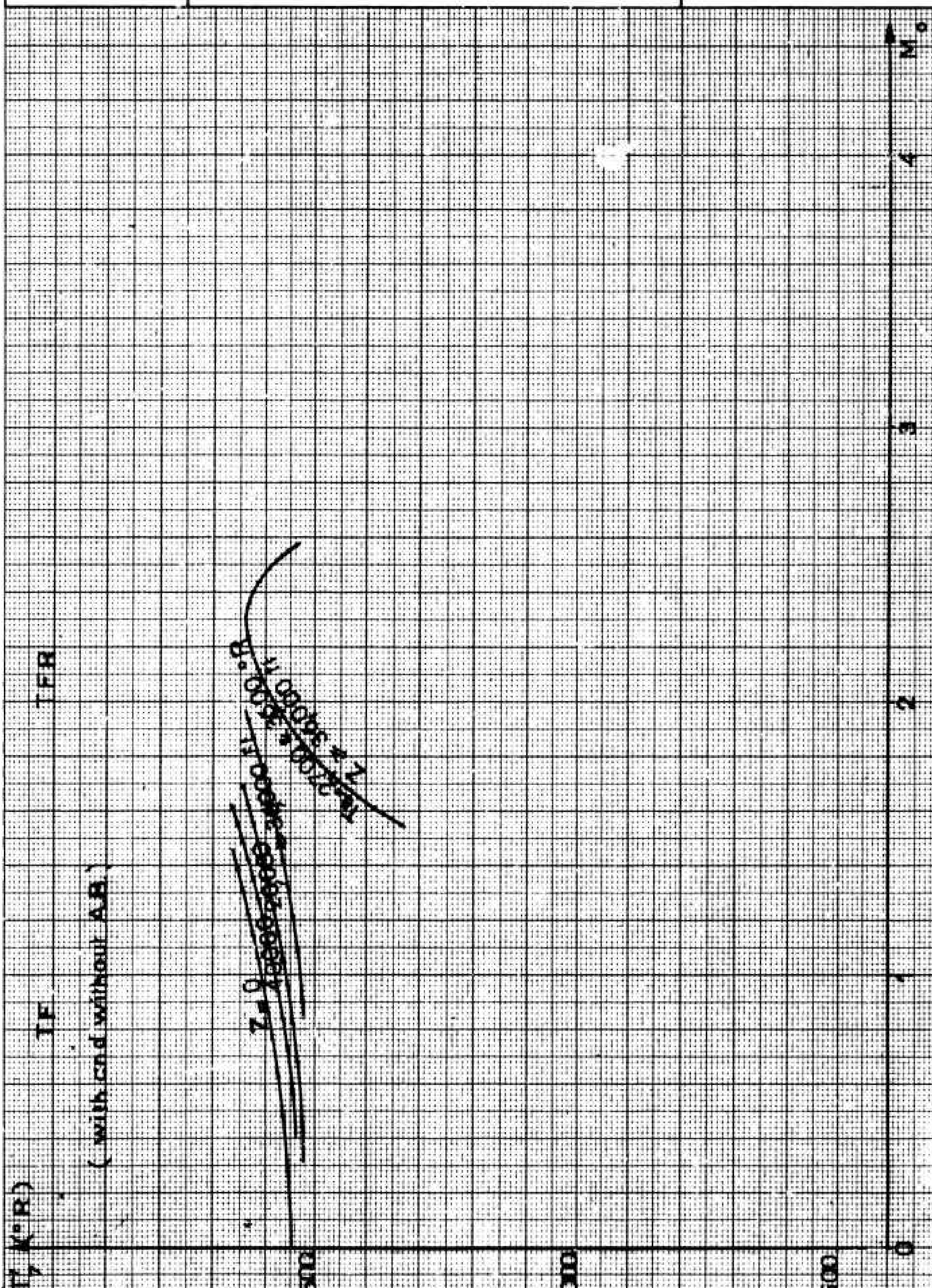
Nord-Aviation	FAN EXIT TOTAL TEMPERATURE	5153/NIOBE IV/35/Z
		Figure 7



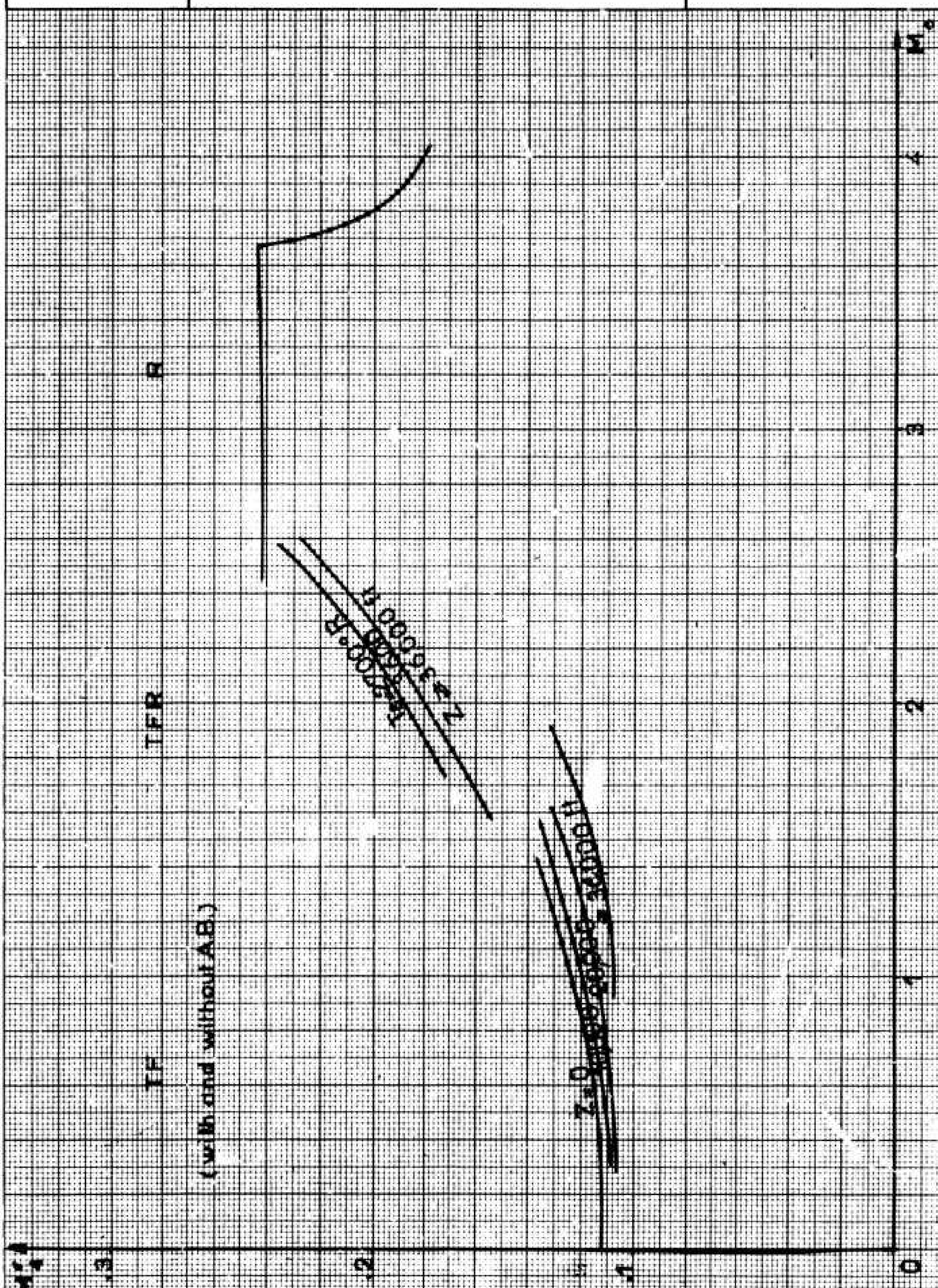
Nord-Aviation	PILOT BURNER INLET TOTAL TEMPERATURE	5153/NIOBE IV/35/Z Figure 8



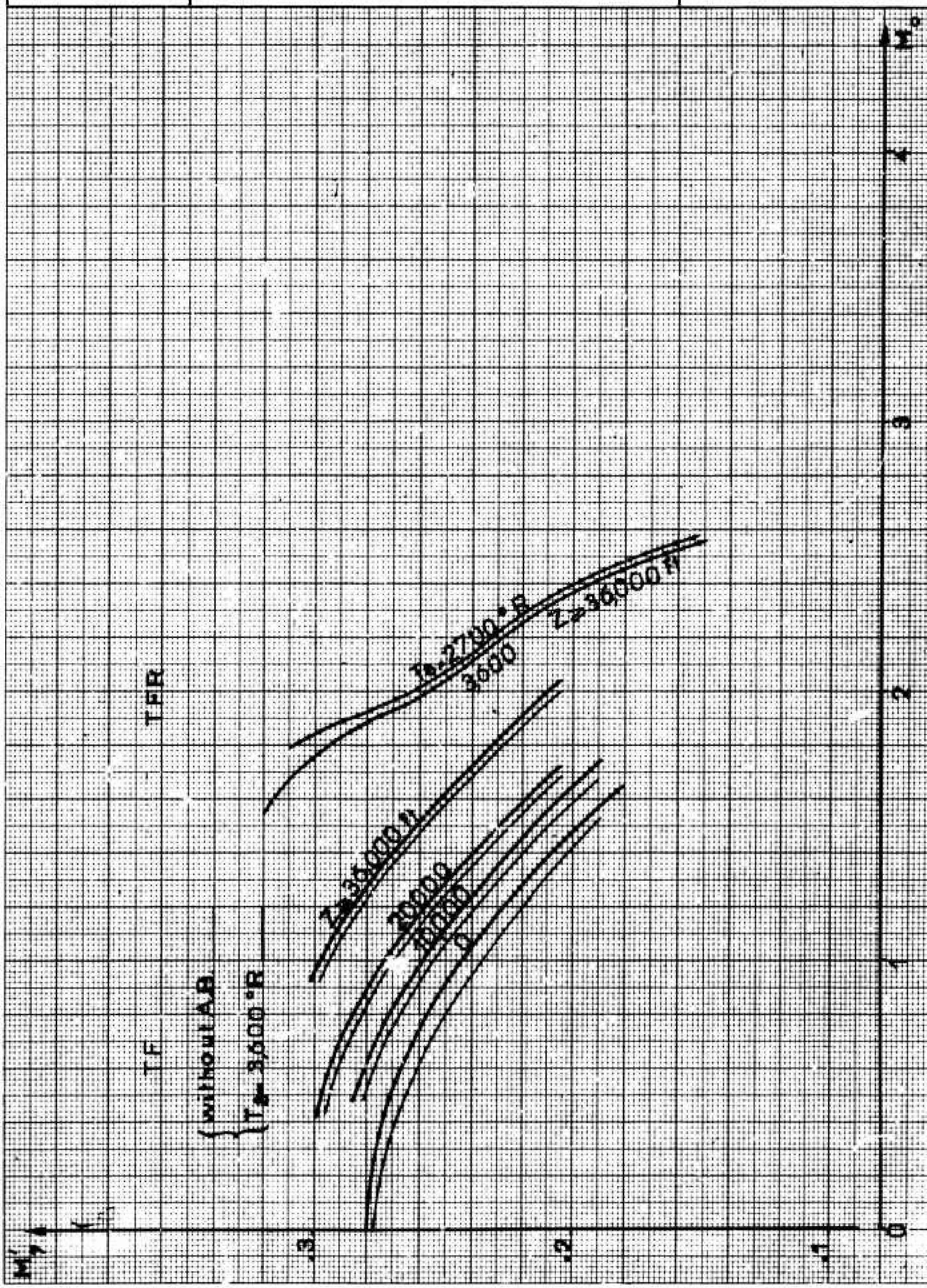
Nord-Aviation	PRIMARY EXIT TOTAL TEMPERATURE	5153/NIOBE IV/35/Z
		Figure 9



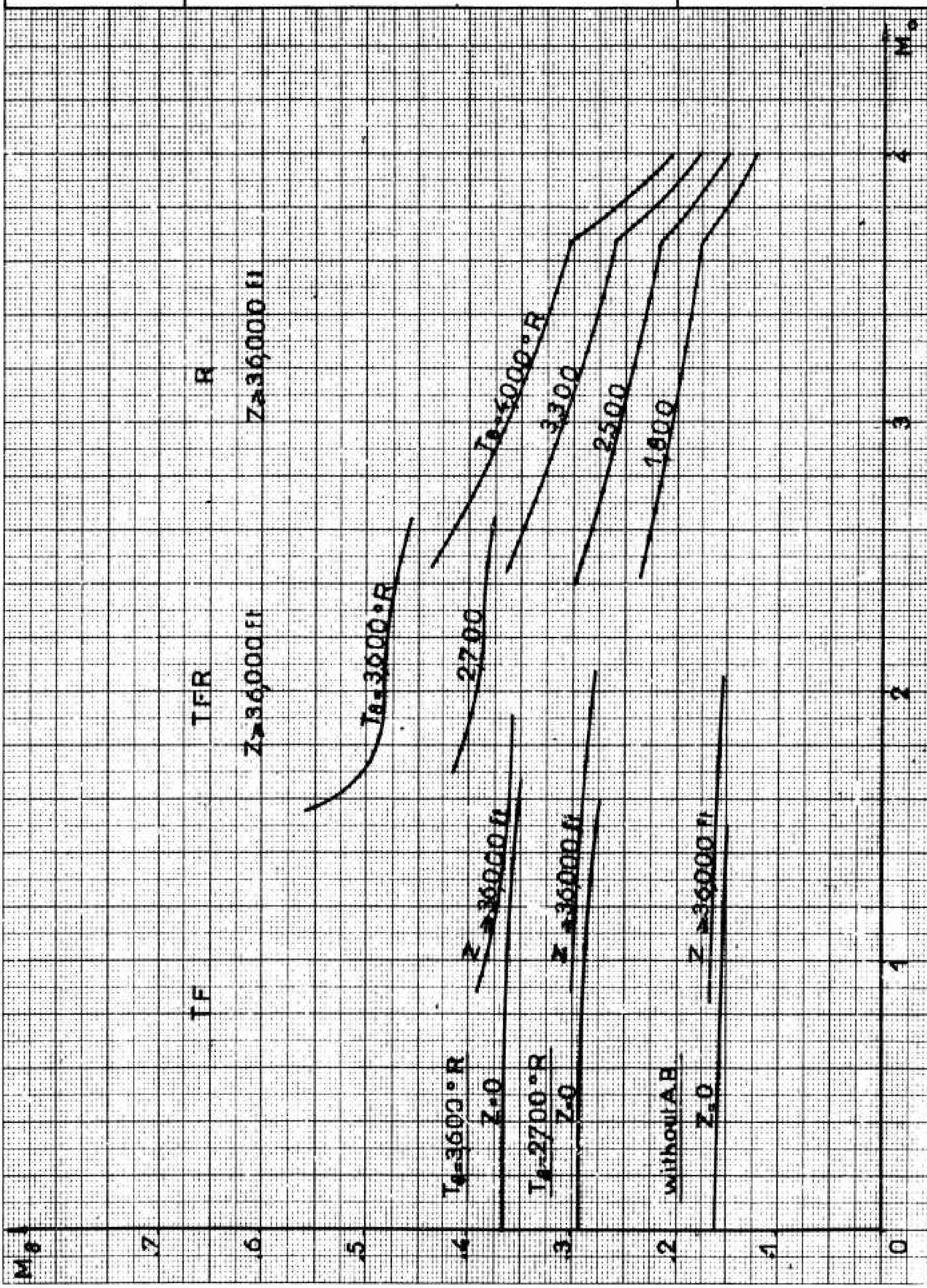
Nord-Aviation	PILOT BURNER INLET MACH NUMBER	5153/NIOBE IV/35/Z
		Figure 10



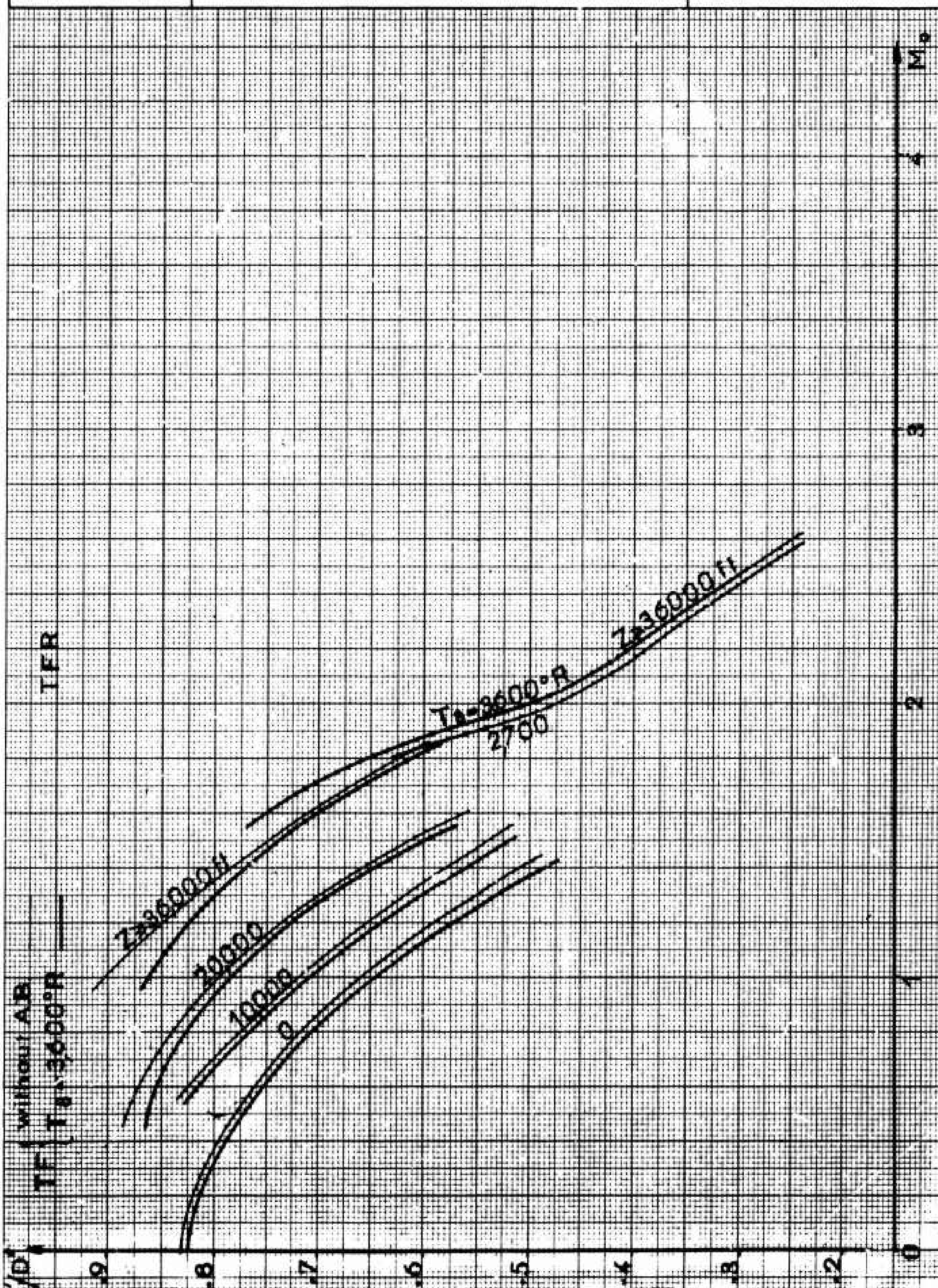
Nord-Aviation	PRIMARY EXIT MACH NUMBER	5153/NIOBE IV/35/Z
		Figure 11



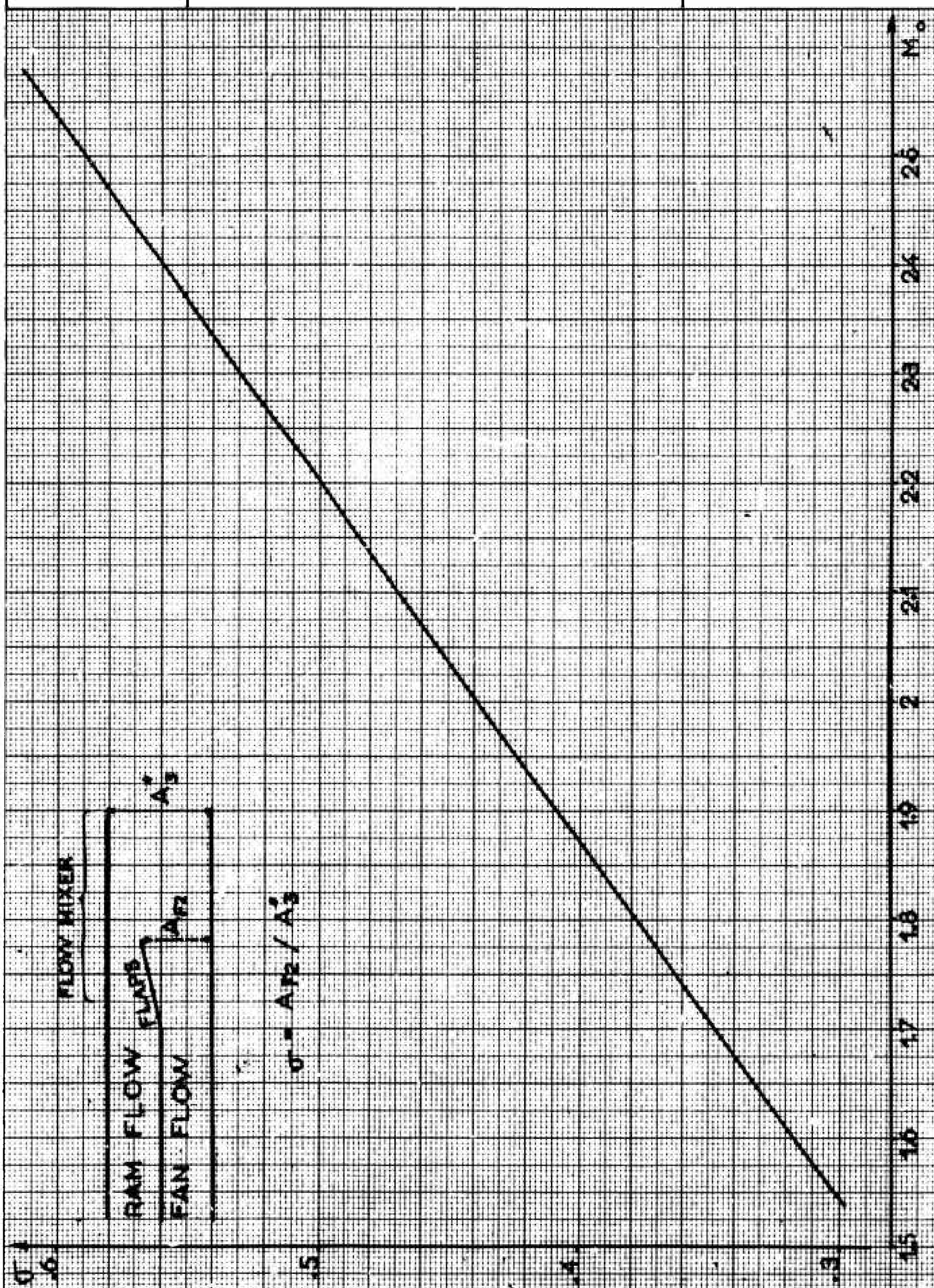
Nord-Aviation	MACH NUMBER AT THE COMBUSTION CHAMBER EXTREMITY	5153/NIOBE IV/35/Z
		Figure 12



Nord-Aviation	PRIMARY / ANNULAR FLOW RATIO	5153/NIOBE IV/35/Z
		Figure 13



Nord-Aviation	FLOW MIXER	5153/NIOBE IV/35/Z Figure 14



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13. ABSTRACT
The performance characteristics of the turbofan-ramjet combination engine are calculated in three configuration: pure turbofan (subsonic and transonic rating), turbofan-ramjet (moderate supersonic), and pure ramjet (high supersonic). The results are presented in graph form and show the engine optimum operating point and the internal engine conditions at the different stations.

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